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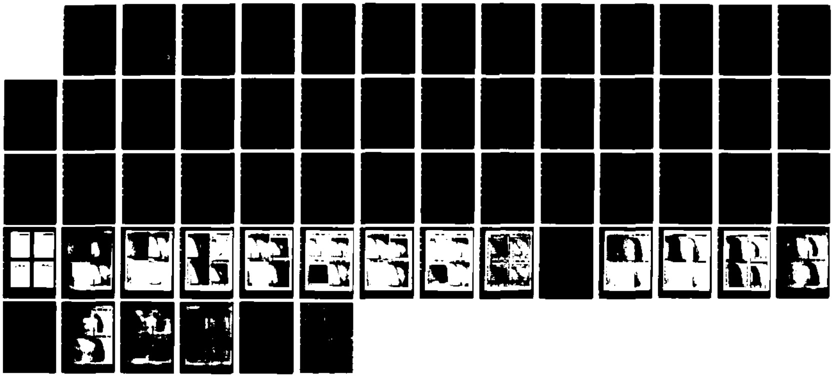

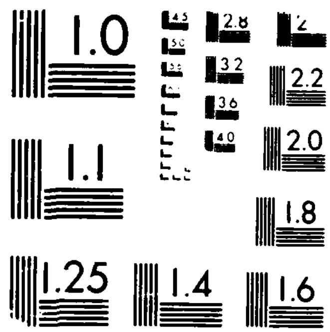

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Satellite UV Image Processing

Norman Rosenberg

Northwest Research Associates
P.O. Box 3027
Bellevue, WA 98009

9 October 1987

Scientific Report No. 4

AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AIR FORCE BASE, MASSACHUSETTS 01731

This technical report has been reviewed and is approved for publication.

Lois Wlodyka

LOIS WLODYKA
Contract Manager

for John E. Rasmussen

JOHN E. RASMUSSEN, Chief
Ionospheric Interactions Branch

FOR THE COMMANDER

ROBERT A. SKRIVANEK, Director
Ionospheric Physics Division

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The overall objective of the program is the photometric and geometric processing of UV satellite images. The data source is the AIRS scanning UV spectrometer aboard the POLAR BEAR satellite. The processing is designed to provide geographic-mapped images which describe the spatial and temporal variability of airglow and aurora of emitting species.

The AIRS data stream provided simultaneous records from 3 detectors received at several ground stations from several passes per day. These total about 1500 useful images from launch to Feb. 1987.

The major progress during the report period has been development of programs to accomplish the following: (1) Statistical filtering of low-count images to provide meaningful brightness estimates; (2) Use of observed limb locations to provide attitude correction in daylit images and attitude estimation in night images to provide accurate ground positions; (3) Normalization of air-

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19. Abstract (Continued.)

glow based on column path length and solar flux which allows separation of aurora from airglow portions of the images; (4) Multi-band presentation of auroral features which clearly define differences between the location of emitting species.

Table of Contents

1.0 Introduction

The overall objective of the program is the photometric and geometric processing of UV satellite images. The data source is the AIRS scanning UV spectrometer aboard the POLAR BEAR satellite. The processing is designed to provide geographic-mapped images which describe the spatial and temporal variability of airglow and aurora of emitting species.

An understanding of this variability, modeled with appropriate ground-based measurements, may provide maps of electron density and ionospheric propagation paths.

The AIRS data stream provided simultaneous records from 3 detectors received at several ground stations from several passes per day. These total about 1500 useful images from launch to Feb 1987 when the satellite lost attitude stability.

The objective of the current 3-month project has been to:

(1) Evaluate the geometric and photometric quality of the AIRS data collected in the period 1 Jan 1987 through 28 Feb 1987.

(2) Provide a standard processing from the time-spaced data stream to geographic coordinates of a photometrically-standardized image which will clearly show the relative auroral activity in each detector.

(3) Provide an analysis of the dependence of the observed count on path-length and on solar flux to aid in modelling the airglow kinetics.

The major progress during the report period has been development of programs to accomplish the following:

(1) Statistical filtering of low-count images to provide meaningful brightness estimates.

(2) Use of observed limb locations to provide attitude correction in daylit images and attitude estimation in night images to provide accurate ground positions.

(3) Normalization of airglow based on column path length and solar flux which allows separation of aurora from airglow portions of the images.

(4) Multi-band presentation of auroral features which clearly define differences between the location of emitting species.

(5) Batch processes which will take a given record from raw input to final mapped aurora and airglow, and analysis of spatial dependence.

This report presents a brief summary of each topic followed by a series of Appendices which provide more detailed discussion of each topic.

Appendix 1 presents a summary of programs developed during the report period.

2.0 Data Sources

The image data is merged with the orbital position and attitude data into a specified format on a PC diskette, which is the raw input for the processing system described below.

The raw image data in each detector is a count of sub-satellite column brightness sampled at 7 millisec intervals during a 135 degree mirror scan around nadir over a 3 second period. Each detector isolates emission in a narrow wavelength band characteristic of a distinct emitting species and process.

This scan presents a horizon-to-horizon record of 4000 km across the orbital path. A typical record from a station during a satellite pass includes about 200 scan lines taken over 600 seconds representing a 4000 km along-orbit track.

The program RAWCVT has been rewritten to convert this raw diskette into a 240 line x 240 column image, an orbital data file and a wavelength file. The program copes with data gaps and tests whether the raw data is packed. If packed, program UNPAK is invoked to generate a non-saturated image.

Appendix 2 lists details of this program.

3.0 Statistical filtering of low-count images

Count rates in all detectors were usually in the 0 to 10 range and rarely exceeded 20. This data is best treated as a Poisson process. A count of 1 has a 100 pc error and a count of 10 a 30 pc error. The error can be reduced to 10 pc by 'lumping' samples until 100 counts are accumulated, effectively trading spatial resolution for a statistically-acceptable error. A program FILTRAW was developed which provides the necessary tradeoff at each point of the image, while preserving the original percentile distribution.

Appendix 3 lists details of this program.

4.0 Attitude data

During observation when the satellite is in sunlight, attitude is derived from a magnetometer and solar-aspect sensor with about $\pm$ 2 degree accuracy and reported for each 3-second scan. Pitch, yaw and roll showed 5-15 minute cycle amplitudes ranging from 0 to several degrees.

At other times, no attitude data is available from the satellite.

However, a bright limb is observed from the emitting layer and a program ROLADJ has been developed to estimate the roll required to place the limb at a defined altitude. In several images, both limbs are visible and defined the emitting layer height as 150 $\pm$ 20 km.

The roll defined by the limb showed about a 1.5 degree offset from the available magnetometer-reported rolls.

The average roll adjustment for each of the cases tested was:

Code	2	3	4	5	6	7	8	10	11	12	13	14
Rol-adj	1.7	1.0	1.8	2.0	2.2	1.5	1.6	2.8	3.6	1.0	2.3	5.0

Appendix 4 lists details of this program.

5.0 Geometric mapping of the raw image

The observed count came from the line-of-sight determined by mirror scan angle and satellite attitude. At angles near nadir, this is a near-vertical column from satellite to ground. As the scan angle increases, the column is more oblique and above 60 degrees from nadir does not reach the ground but continues into space. Near the left and right edges of the raw image where this condition applies, some samples are not intercepting the ground and cannot be mapped onto earth coordinates.

At angles where the line-of-sight scan intercepts the ground, there is a single oblique intercept with the emitting layer at about 150 km, which will be closer to satellite nadir than the ground intercept distance.

Program GEOMIM and SOLEL have been written to compute for each image point:

(1) The geographic coordinates

(2) The local solar flux = sin (solar elevation)

(3) The oblique path length relative to vertical which reaches about 5 x the vertical path at the ground tangent. Raw samples at larger scan angles cannot be assigned ground coordinates.

A program WARPIM has been written to 'warp' the image from the input sample coordinates to ground coordinates.

Appendix 5 lists details of this program.

6.0 Normalization of Airglow

A program GEOMLSQ has been written to test the dependence of airglow intensity on the path length and solar flux.

The program found the dependence of count on some power of path and some power of solar flux.

cnt = C0 * (path ** -Cp) * (sin(solel) ** Cs)

in sunlight by a least square fit of

log10(cnt) = C0 + Cp * log10(1/path) + Cs * log10(sin sol elev)

and in dark by

log10(cnt) = C0 + Cp * log10(1/path)

Detector 2 (1356 A) was the only group with a count which did not require very heavy smoothing. In this group, the observed count of non-auroral sunlit points was well-fitted to an expression proportional to path length (optically-thin) and to sqrt (solar flux). The non-sunlit airglow did not show this path dependence (optically-thick?). The other detectors were so weak that no reliable fit was possible. These facts should be useful in defining the kinetics of the emission process.

Table 1 shows the outputs of GEOMLSQ on the cases listed for each detector for sunlit and non-sunlit portions of the image.

Table column headings are:

cod	code of scene
LMT	local mean time
pcsl	percent sunlit (sol elev > 0.01)
pcau	percent aurora (from geomlsq fit)

Table 1 Summary of geomlsq results on 13 scenes
prepared by REPLSQ

sunlit det=2 wvl=1356

cod	day	LMT	pcsl	pcau	C01	Cp	Cs	sg0	pcvf	pcvx	Ray
02	023	11.50	54	11	13.0	-0.79	0.34	0.180	13	14	63
03	023	11.48	41	14	26.2	-0.55	0.16	0.130	40	54	101
04	042	10.22	77	10	10.9	-0.84	0.34	0.200	15	15	56
05	043	10.13	62	10	7.2	-0.93	0.48	0.260	11	11	31
06	047	9.86	63	12	9.6	-0.83	0.40	0.220	15	14	48
07	048	9.79	65	10	9.1	-0.93	0.40	0.230	14	14	43
08	055	9.30	68	11	8.8	-0.79	0.43	0.230	16	19	43
10	058	9.04	49	21	12.3	-1.26	0.39	0.280	13	15	36

no_sun det=2 wvl=1356

cod	day	LMT	pcsl	pcau	C01	Cp	Cs	sg0	pcvf	pcvx	Ray
02	023	11.50	54	11	6.3	-1.25	0.00	0.290	51	0	30
03	023	11.48	41	14	5.6	-1.79	0.00	0.400	34	0	21
04	042	10.22	77	10	4.1	-1.94	0.00	0.390	21	0	21
05	043	10.13	62	10	4.9	-0.32	0.00	0.130	87	0	21
06	047	9.86	63	12	5.8	-0.13	0.00	0.140	99	0	29
07	048	9.79	65	10	4.4	-2.03	0.00	0.400	15	0	21
08	055	9.30	68	11	4.0	-1.49	0.00	0.300	20	0	19
10	058	9.04	49	21	6.9	-1.10	0.00	0.270	66	0	20
11	025	23.55	0	29	22.0	0.34	0.00	0.290	96	0	43
12	024	23.62	0	26	33.3	0.94	0.00	0.390	78	0	98
13	029	23.27	0	27	34.1	0.78	0.00	0.450	89	0	185
14	032	23.05	0	33	34.1	0.86	0.00	0.410	86	0	113
15	043	22.30	0	18	42.8	0.73	0.00	0.380	89	0	299

sunlit det=1 wvl=1596

cod	day	LMT	pcsl	pcau	C01	Cp	Cs	sg0	pcvf	pcvx	Ray
02	023	11.50	54	15	20.5	-0.57	0.31	0.170	37	49	32
03	023	11.48	41	17	55.9	-0.24	-0.01	0.130	89	166	85
04	042	10.22	77	11	14.4	-0.65	0.34	0.190	30	43	27
05	043	10.13	62	13	9.5	-0.82	0.38	0.230	18	25	22
06	047	9.86	63	17	17.0	-0.65	0.29	0.180	34	46	29
07	048	9.79	65	15	11.8	-0.72	0.32	0.200	26	41	27
08	055	9.30	68	17	11.0	-0.58	0.39	0.200	29	47	25
	058	9.04	49	19	13.6	-1.25	0.37	0.330	20	22	15

no_sun det=1 wvl=1596

cod	day	LMT	pcsl	pcau	C01	Cp	Cs	sg0	pcvf	pcvx	Ray
02	023	11.50	54	15	7.7	-1.36	0.00	0.280	32	0	12
03	023	11.48	41	17	8.3	-1.55	0.00	0.360	36	0	13
04	042	10.22	77	11	7.0	-1.63	0.00	0.300	30	0	13
05	043	10.13	62	13	5.3	-0.60	0.00	0.140	71	0	12
06	047	9.86	63	17	7.2	-0.71	0.00	0.150	73	0	12
07	048	9.79	65	15	5.7	-1.86	0.00	0.360	21	0	13
08	055	9.30	68	17	5.0	-1.45	0.00	0.280	27	0	12
10	058	9.04	49	19	11.8	-0.66	0.00	0.210	83	0	13
11	025	23.55	0	35	11.8	-1.01	0.00	0.400	78	0	9
12	024	23.62	0	43	16.8	0.52	0.00	0.310	90	0	27
13	029	23.27	0	34	9.7	-0.40	0.00	0.380	96	0	22
14	032	23.05	0	35	10.4	-0.60	0.00	0.450	94	0	18
15	043	22.30	0	22	37.1	0.76	0.00	0.440	91	0	829

no_sun det=3 wvl=3914

cod	day	LMT	pcsl	pcau	C01	Cp	Cs	sg0	pcvf	pcvx	Ray
11	025	23.55	0	28	22.3	-0.17	0.00	0.130	94	0	539
12	024	23.62	0	31	21.6	0.35	0.00	0.220	91	0	977
13	029	23.27	0	39	10.9	-0.06	0.00	0.260	100	0	1026
14	032	23.05	0	34	12.5	-0.51	0.00	0.320	91	0	873
15	043	22.30	0	33	26.5	0.82	0.00	0.270	69	0	3023

C01 count in amplified filtered image normalized to path length 1 and in sunlit cases to a sin(solar elev) of 0.01

Cp lsq fit 1/path dependence

Cs lsq sin(sol_elev) dependence

sg0 stdvn of input points in log10 units (0.13 equiv to + 30%)

pcvr percent of variance remaining after fit (i.e. 10 pc equivalent to reduction of stdvn to 30 pc of input)

Note that if the pcvr is above 50 pc, the data scatter is so high that there is no significant dependence on the parameters

pcvx percent of variance remaining after fit forcing Cp to -1 and Cs to 0.5

Note that if pcvx is close to pcvr, the force fit is as valid as the 'free' lsq fit

Ray the Rayleigh count normalized from C01 correcting for amplification from raw to filtered count and the detector sensitivity (Rayleighs/orig count)

Appendix 6 lists details of this program.

7.0 Multi-band presentation of auroral features

As noted above, it is possible to define the airglow relationship to solar flux and path length. However auroral features do not match the expressions and may be 'feature-extracted' from the airglow and separately presented.

The relative intensity of local aurora in two bands may most clearly be shown after a histogram-equalization program HISEQ is performed. By this process the lowest 1 percentile is converted to relative intensity 1, the 50 percentile to 50, and the 99 percentile to 99. In practice the relative intensities are scaled 0-255.

The two bands can be co-displayed by a program MULBND as a 2-color image with one band in red and the other in green. If the two bands match, a yellow image of a given intensity will be displayed, else a tendency to red or green will be displayed. In practice, the program adds a 'blue' signal equal to the weaker of the two signals so the matched color 'yellow' is seen as shades of grey from black to white. (The problem of subtracting one detector signal from another as a 'contaminant' has not yet been addressed.)

Appendix 7 lists details of this program.

8.0 Batch processes

Mulp.bat carries a given detector through all steps required by the flowsheet after roladj to produce labelled images as disk files. Preparation of a full group of 32 display images from a pair of input detectors takes about 15 minutes. Required inputs for Mulp.bat are a pair of raw image files and data files rawNN.d, wvlNND.d, and rajNN.d roll adjustment.

Muld.bat displays the labelled images for demonstration purposes. After photography of appropriate images, the image files should be deleted because of heavy disk usage.

Appendix 8 lists details of these batch files.

9.0 Photographs

Photographs from the monitor screen demonstrating various stages in the processing are reported in Appendix 9.

APPENDIX 1. Programs, Data base structure, and Flowsheets

Appendix 1-a. New or modified source programs

Program	Type	Use
BEEP	Util	Beeps to console
CB	Util	Beautify C program
CBDIAG	Util	Diagnose C program
CLEANIM	AIR	Remove isolated high noise points from image
DIFFIM	Img	Difference between 2 images
DIRFMT	Util	Modify dir listing
DIROS	Util	Modify dir listing to provide bat file for del or copy
DIRDUP	Util	Find dup files in full dir listing
FFTAUR	AIR	Test for amplitude in aurora after filter
FILTIM	Img	Filter smoothing with possible threshold
FILTRAW	AIR	Narrow and wide smooth combine to filtered image
FINDX	Util	Find and print lines not containing phrase
FULLDIR	Util	Generate full listing of disk from 'TREE' listing
GEOMIM	AIR	Generate matrix of ground coord for raw image points
GEOMLSQ	AIR	Least sq fit of brightness to path len and sol flux
GRAF	Util	Graph input data set
GRAFIM	Img	Graph to image selected image line brightness
GRIDIM	Img	Overlay grid on image
HISEQ	Img	Histogram equalize image
INITIM	Img	Initiate image board
LANDMASS	Img	Overlay landmasses and lat/lon cord on image
MEDIAN	Img	Median image
MOUSE	Img	Provide print around moveable cursor mouse on image
MODIM	Img	Stretch rotate 1-d smooth image
MOVEIM	Img	Move image from qd to qd or disk to qd or qd to disk
MULBND	AIR	Two-color output from 2 input bands
NEWSCL	Img	Rescale image brightness
OVERLIM	Img	Overlay image (landmass) onto image
PATCH	Img	Patch noisy segments from image
PAUSEX	Util	Pause in program
POISCMP	AIR	Compute Poisson statistics
POISEST	AIR	Estimate Poisson statistics
POISSON	Img	Generate Poisson statistics
PRINTIM	Img	Print vals from image
RAWCVT	AIR	Convert Raw diskette to image file
RAWFIT	AIR	Reprocess raw orbital parameters
REFMT	Util	Reformat file
REPAK	Img	Pack/unpack log expansion
REPLSQ	AIR	Summarize all lsq files
ROLADJ	AIR	Compute correct roll from limb location
ROTIM	Img	Rotate or squish image
SNAPIM	Img	Snaps to quadrant
SNAPINT	Img	Snaps and integrates to quadrant
SOLEL	AIR	Compute solar elev for each point in image
TEXTHDR	AIR	Extract text from hdr file and overlay for demo
TEXTIM	Img	Label Image
UNPAK	AIR	Unpack packed satellite data
WARPIM	AIR	Warp raw image to ground coordinates
ZOOMIM	Img	Zoom image to quad or 1/4 quad

Appendix 1-b. Scene Processing Flowsheet for AIRS

The flowsheet below shows processes and input and output files generated for a given scene. A scene NN (coded by a 2-character symbol, 01-ZZ possible) is defined as a multi-detector record for a given site, day and pass.

The geographic data files are required for processing each individual detector image. These data are common to all detectors and are generated by this flowsheet.

INPUTS		PROCESS	OUTPUTS	
Data	Images		Data	Images
RAW DISKETTE		rawcvt	RAWNN.d WVLNND.d	RAWNND.i
RAWNN.d		rawfit	FILNN.d HDRNN.d	
FILNN.d HDRNN.d		roladj	RAJNN.d	
RAWNN.d RAJNN.d		rawfit	FILNN.d HDRNN.d	
FILNN.d		geomim	GEONN.d	
GEONN.d		solel	SELNN.d	
GEONN.d SELNN.d		warpim		SELNN.i
HDRNN.d		landmass		LHNN.i

Appendix 1-c. Detector Processing Flowsheet for AIRS

The flowsheet below shows processes and input and output files generated for photometric processing for each useable detector in a given scene. The individual detector files are coded NND where D is expected to have a value 1 to 4.

The geographic data files are combined with the detector files to provide geographically-oriented 5000 x 5000 km scenes.

INPUTS		PROCESS	OUTPUTS	
Data	Images		Data	Images
	RAWNND.i	unpak	UNPNND.d	UNPNND.i
	UNPNND.i	filtraw		FILNND.i
GEO NN.d GEO NN.d	FILNND.i	warpim op1	AMPNND.d	
HDRNND.d AMPNNd.d UNPNND.d	SELNN.i WARNND.i	geomlsq	LSQNND.d	AGLNND.i AURNND.i
	AURNND.i	hiseq		AUHNN.i
	AUHNN1.i AUHNN2.i	mulbnd		AURNN12.i
	LHNN.i AUHNN1.i AUHNN2.i AURNN12.i	overlim texthdr		DISNN1.i DISNN2.i DISNN12.i
		photographs for publication		
	any image	grafim	graphed count along sampled lines	
		photographs for publication		

APPENDIX 2. Conversion of raw diskette to image and data files

RAWX.BAT file to process several groups of input diskettes

```
goto aa
del \air\raw13.d
pausex insert diskette sn87029.d3 for raw133
rawcvt s87029 133 es4420 < a:sn87029.d3
moveim 15 \air\raw133.i
pausex insert diskette sn87029.d2 for raw132
rawcvt s87029 132 es4420 < a:sn87029.d2
moveim 15 \air\raw132.i
pausex insert diskette sn87029.d1 for raw131
rawcvt s87029 131 es4420 < a:sn87029.d1
moveim 15 \air\raw131.i
:aa
del \air\raw14.d
pausex insert diskette sn87032.d3 for raw143
rawcvt s87032 143 es16050  < a:sn87032.d3
moveim 15 \air\raw143.i
pausex insert diskette sn87032.d2 for raw142
rawcvt s87032 142 es16050  < a:sn87032.d2
moveim 15 \air\raw142.i
pausex insert diskette sn87032.d1 for raw141
rawcvt s87032 141 es16050 < a:sn87032.d1
moveim 15 \air\raw141.i
```

RAWCVT help

```
USAGE rawcvt SYYDDD NND (raW bsB esF ssS fsS lpL hpH) < ASCII
EXAM     rawcvt S86338 011 < A:S87008h2.dat
 INPUTS   ASCII file with original BC file format
 OUTPUTS  in \AIR directory
          rawNN.d if not exist else check vs   rawNN.d
          wvlNND.d with wvln of detector D image
          qd=2 xfered to qd=1 (rot if necessary)
   SYYDDD   converted in rawfit to site yr and day
   NND      AIR code and detector
stretches input to image (240 line x 240 col)
estimates lines from file header start and final sec
  if conflict report start and final sec in line hdr
  can rerun with options ssS and fsS described below
  save image by 'moveim 15 rawNND.i'
options if present
  raW W=1 output q1 raw data 326 cols x input lines
  bsB flags begin sec for image (if bad section)
  esE flags end   sec for image (if bad section)
  ssS S= start sec to override header start sec error
  fsS S= final sec to override header final sec error
  lpL hpH low high input kol with non-zero (def=5 330)
  bgB B=2 quits after hdr read
```

Terminal print from RAWX.BAT

```
C:\BOB1>pausex insert diskette sn87043.d3 for raw153
insert diskette sn87043.d3 for raw153  continue..
C:\BOB1>rawcvt s87043 153 es4190 < a:sn87043.d3
C:\BOB1\BIN\RAWCVT.EXE s87043 161 es4190
opening junkraw for diagnostics
```

```
opening new scene file \air\raw16.d
opening detector file \air\wvl161.d
writing wvl  1596
raw SS=3805.1 FS=4501.1 sec=696.0 lines=233
req BS=3805.1 ES=4190.0 sec=384.9 lines=129
adjusted ESEC to= 4189.10
final write at CSEC=4189.1  lin=128 lwp=238 lwr=240
ilin 129 lwr 240 ESEC=4189.1 CSEC-ESEC=   0.0
report min(9,cnt) for val= 0-60 if unpacked 33 35 37 zero
val 0    5    10    15    20    25    30    35    40    45    50    55    60
cnt 9999999999993322043000101200000000000000000000000000000000000
No errors in rawcvt
Rotate image for N up
```

File junkraw generated by rawcvt

```
raw SS=3805.1 FS=4501.1 sec=696.0 lines=233
req BS=3805.1 ES=4190.0 sec=384.9 lines=129
adjusted ESEC to= 4189.10
  raw   out  rawNN  curr    imag   read   true   calc
  lin   lwr  prnt   CSEC    RSEC   dsec   l_rd   l_wr
    0     0    1    3805.1   0.0    0.0    0.0    0.0
    1     2    1    3808.1   3.0    3.0    1.0    1.9
    2     4    1    3811.1   6.0    3.0    2.0    3.7
    5     9    2    3820.1  15.0    3.0    5.0    9.3
    .
    .
  125   233  38     4180.1 375.0    3.0  125.0  232.6
  126   234  38     4183.1 378.0    3.0  126.0  234.4
  127   236  38     4186.1 381.0    3.0  127.0  236.3
  128   238  39     4189.1 384.0    3.0  128.0  238.2
  final write at CSEC=4189.1  lin=128 lwp=238 lwr=240
  ilin 129 lwr 240 ESEC=4189.1 CSEC-ESEC=   0.0
  report min(9,cnt) for val= 0-60 if unpacked 33 35 37 zero
  val 0    5    10    15    20    25    30    35    40    45    50    55    60
  cnt 9999999999993322043000101200000000000000000000000000000000000
  No errors in rawcvt
Rotate image for N up
```

APPENDIX 3. Amplification and filtering of raw image

```
USAGE filtraw (nW wW sS pP fF)
  input q1 amplifies and smooths
  outputs q2=aurora q3=airglo q4=final
  reports final amplification in file junkamp
    pP P=pcaur  pct image with narrow smth wid (def=25)
    nW W=narrow smoothing width (for  aurora)
    wW W=wide   smoothing width (for airglow)
    sS number smths
    fF F=final value wanted at pcaur
       defaults n3 w19 s1 f50
       if set n0 w0 s0 f0 selects n w s f
EXAM filtraw
EXAM filtraw n3 w9 s1 p10
```

Comparison of image count with Poisson distribution

A Poisson distribution is expected for a random process where the sample rate is high compared to the count rate.

The expression for probability of count N in a Poisson process is

P(N)= SAV ** N / N! * exp(-SAV)

with both standard deviation and signal/noise ratio (SNR) = sqrt(SAV)

As an example, if a count rate of 100/sec is sampled at a rate of 100/sec the average count per sample (SAV = tot counts/tot samples) will be 1 with a distribution of about 37% with count 0, 37% with count 1 and 18% with count 2. (The Poisson expression approaches a Gaussian distribution at high SAV values.) Table 1 presents selected values of Poisson statistics.

Table 1. Poisson probabilities for selected sample average count.

SAV sample average count
P(N) 1000 * probability of count N

SAV	N =	0	1	2	3	4	5	6	7	8	9	10	11	15	20	25
0.01	P(N)=	990	9													
0.03	P(N)=	968	30													
0.1	P(N)=	904	90	4												
0.3	P(N)=	728	230	36	3											
1	P(N)=	367	367	183	61	15	3									
3	P(N)=	42	133	211	223	176	111	58	26	10	3					
10	P(N)=	0	0	2	7	18	37	63	90	112	125	125	113	34	1	
20	P(N)=	0	0	0	0	0	0	0	0	1	2	5	10	51	88	34

To achieve reasonable SNR = sqrt(SAV) it is possible to tradeoff time (or spatial) resolution by increasing the sample period, or equivalently to sum enough samples to increase the sample average SAV. Specifically, the SNR = 3 if enough samples are summed to bring SAV to 10 and SNR = 10 if SAV is brought to 100.

AIRS images

Are the low-count AIRS images typical Poisson processes? Table 2 presents the statistics for a night AIRS image in each of 3 bands. The data confirm that at the low-count region of the images are closely approximated by Poisson distributions.

This implies that variable-area summing must be performed using different summing areas for different SAV regions. The area will be 100/SAV pixels for SNR = 10. Such a summing is in fact a smoothing (or averaging) process and each summing area leads to a different image.

In practice, two smoothing areas are sufficient for most purposes. A large-smoothing area image based on the low-count region and a smaller-smoothing area image based on the high-count area. The final output uses the value from the narrow-smoothed image if it is above the narrow-smooth threshold, else from the wide-smoothed image.

Notes on the smoothing process

The original image is first 'amplified' by a constant determined from the input histogram to bring the 99 percentile value to a value of 200. This is necessary because averaging a 50 pixel area containing 90 percent 0's and 10 percent 1's will yield zero but if the 1's have been amplified to 50's, a meaningful value of 5 will be obtained.

It is more efficient to carry out two 1-dimensional smoothings than an area smoothing. A horizontal (line-by-line) smoothing of input is followed by a vertical smoothing of the first output. The smoothing width in each direction will be the sqrt of the desired smoothing area.

Table 2. Comparison of Poisson and AIRS Scene Count distribution in non-auroral regions of a nightime scene.

cmpc	100	64	50	42	27	16	10	6.5	4.3	2.7	1.7	1.0	0.7
lgfr	0	20	30	40	60	80	100	120	140	160	180	200	220

wvln=1544 SAV = 0.04 N 50 = 0.20

P_10*n	0	1	2	2	4	5	6	8	9	11	13	15	16
S_10*n	0	1	2	2	4	5	6	8	9	11	15	18	24
Ob/Ex	-	100	100	100	100	100	100	100	100	100	115	120	150

wvln=1304 SAV = 0.85 N 50 = 1.10

P_10*n	0	8	11	13	18	22	25	28	32	34	37	40	44
S_10*n	0	8	11	13	18	22	26	29	33	36	40	44	48
Ob/Ex	-	100	100	100	100	100	104	103	103	105	108	110	109

wvln=3914 SAV = 2.63 N 50 = 2.90

P_10*n	0	23	29	33	41	47	52	57	62	66	71	75	79
S_10*n	0	22	27	32	40	48	56	65	76	91	112	138	171
Ob/Ex	-	95	93	96	97	102	107	114	122	137	157	184	216

Explanation of symbols:

cmpc — is the cumulative percent with count >= N. Ranges from 1000 at N=0 to low values at high N

lgfr — log fraction remaining reported as 100 * log10 (100/cmpc). N is a linear function of lgfr for small SAV

wvln — Wavelength of image

SAV — Sample average = total counts/total samples

N_50 — Interpolated N for 50 cumulative percent of samples

P_10*n — The expected Poisson N interpolated to selected lgfr and reported as 10 * N.

S_10*n — The scene distribution of N interpolated to selected lgfr and reported as 10 * N.

Ob/Ex — The ratio of Observed Scene to Expected Poisson N reported as percent Scene N/Poisson N

Output from filtraw

```
options-
nsm         number of smooths in each direction
n_wid       narrow smoothing width
w_wid       wide smoothing width
pcau        percent aurora
            (pc image with narrow smoothing width)
lgfr_au     log cum fraction at pcau as  -100.*log10(pcau/100.)
            50pc equiv 30 25pc equiv 60 10pc equiv 100 1pc equiv 200 fin_aur
final value in output image for pcaur
```

```
options nsm=1  n_wid=3 w_wid=19 pcau=25 lgfr_au= 60 fin_aur=50

histog report-
input avg=   6.892 avg/av0=    1.00 highest val=56 iaur=9
input avg=6.892 aur value =9.00 mulau=5.6 to bring fin_aur to 50

lookup table out for inp
inp      0   1   2   3   4   9  40  45  80 120 160 200 240
lut      0   6  11  17  22  50 222 250 255 255 255 255 255

for given cumulative per_mil above-
cmpm  1000 630 501 398 316 251 158 100  63  39  25  15  10   6   3
lgfr     0  20  30  40  50  60  80 100 120 140 160 180 200 220 240
vinp     0 2.7 4.7 6.1 7.6   9  12  17  24  32  36  42  46  46  46
v*mu     0  15  26  34  42  50  69  95 134 176 200 232 255 255 255

   average of values above pcau and estimated smoothing width for
      stdvn=10 pc
   avau=  20.067 est n_wid=2 using n_wid=3
   average of values below pcau and estimated smoothing width for
      stdvn=10 pc
   avag=   3.284 est w_wid=7 using w_wid=19

suggested nsm=1 using nsm=1

result of smooth and readjustments-
first smth i99=237 avg=36.5 iaur=46 anor=1.09 mulau=6.04 iaur=49
output avg=  42.105 avg/av0=    6.11 highest val=255 iaur=51

ratio of out/(inp*amp)
val      1  24  30  36  42  52  69  99 143 182 209 239 253 255 255
v/v0     -  160 115 105 100 104 100 104 106 103 104 103  99 100 100

filtraw amplification is:
 amp_fac=6.109 av_inp=6.892 av_out=42.105
```

Note the amplification finally used is based on unpacked vs filtered values in the area warped onto the ground.

```
Comparison of input and filtered image
          input                          !  filtered
col=      89 100 110 121 131 142 152     !  89 100 110 121 131 142 152
         ----------------------------    ! ----------------------------
l=101      1   0   2   0   4   9  16     !  10  13  19  26  32  68  74
l=109      3   3  13   8   6   9   4     !  20  24  71  38  39  57  34
* 117      8   1   5   3   3   5   2     !  30  32  35  35  32  28  24
l=125      4   6   4   7   7   2   2     !  34  31  28  26  25  24  23
l=133      5   1   2   3   1   3   3     !  32  29  25  24  24  24  24
```

APPENDIX 4. Roll Adjustment

```
USAGE: roladj NN (AIM 11L lhL kwK mxM muM ipR nsM prP rrR yrY buG
       htH nsM dgD + possible overrides psP ysY rsR ksK tsT)
EXAM        roladj 01
EXAM        roladj 01 11100 lh200  mx1
EXAM        roladj 01 ?  (interactive query)
INPUTS      hdrNN.d filNN.d  and image rawNND.i in q1
OUTPUT      \AIR\rajNN.d
```

Eyeball raw images to find detector with best limb and assign 11 lh aurora area to exclude a help1 for full help

Extraction of Adjusted Roll from Image

The roladj program (Limb Horizon)

The program has the objective of determining an adjusted roll angle which will place an observed bright limb at a defined altitude.

Data Processing

For AIRS satellite total scan angle=130.4 deg The deg/image_col= 0.54 from 130.4 scan_deg/240 sample columns. From the satellite_earth geometry for satellite alt=1000 km. The scan angle from nadir to the satellite tangent to ground= 60.0 deg. The scan angle from nadir to the satellite tangent to limb as a function of limb height and the distance in columns from limb to ground tangent is as follows:

Relation of limb height to limb_limb
width in degrees and image columns

tot	deg	col
gnd	119.6	220.0

lmb hgt			each_side col lmb_gnd
100	122.8	226.0	3.0
120	123.4	227.2	3.6
150	124.4	229.0	4.5
170	125.1	230.2	5.1
190	125.8	231.5	5.8
250	127.9	235.3	7.7

In all cases where 2 or more wavelengths showed limbs, the limbs were located within ± 1 column.

In all cases where both limbs were present the limb-limb distance was 230 ± 1 column so a 'best height' estimate is 170 ± 20 km.

Terminal Output from rolladj

```
C:\BOB\BIN\ROLADJ.EXE 06 mx1
hdr  0    AIR     06
hdr  1   Site    SON
hdr  4    LMT   9.86
hdr  9   Radj    0.0

options-
right limb  height=150 kol_limb=239 ll=240 lh=0 mu=2 ipr=1 nsm=3 dg=0

smoothing image from q2 to q2 vertically
found strongest limb line=239 kol=234 britness=161

scan   limb  limb          lm_gd   deg/ sat_ion sat_gnd  pit  yaw roll
ang     ht    col           cols   col   angle   angle
130.4   150 235.1   0.00    4.38   0.54   61.93   59.55  0.9  0.6 -3.9

Note roll is positive for right wing down.

calculation of roll from right limb location                0.1*km gnd
lin  p  y roll            limb ang     limb_col          grnd_col    ! nadir
          inp   out adj lft  rgt  lft  rgt   wid    lft  rgt   wid!  lft rgt

                                      calc found
 0   1   1 -3.9 -2.2 1.6 57.2 61.7 10.0 238.0 228.0  14.7 233.6 219.0 200 200
18   1   3 -3.8 -2.2 1.6 57.2 61.7 10.0 238.0 228.0  14.7 233.6 218.9 200 200
36   1   8 -3.4 -1.3 2.1 58.1 60.8  8.3 236.3 228.0  13.0 231.9 218.9 199 199
54   1   8 -2.6 -0.3 2.3 59.1 59.8  6.4 234.4 228.0  11.2 230.0 218.8 199 199
72   1   3 -1.9  1.0 2.8 60.4 58.5  4.0 232.0 228.0   8.9 227.6 218.7 200 201
90   1  -3 -1.8  0.4 2.2 59.9 59.0  4.9 232.9 228.0   9.8 228.5 218.7 201 200
108 2  -8 -2.5 -0.8 1.7 58.7 60.1  7.0 235.0 228.0  12.0 230.6 218.6 200 199
119 2  -8 -3.1 -1.4 1.7 58.1 60.7  8.0 236.0 228.0  13.1 231.6 218.6 200 199
125 2  -7 -3.3 -2.2 1.1 57.3 61.5  9.5 237.5 228.0  14.6 233.1 218.5 200 199
143 1  -2 -3.8 -2.4 1.4 57.0 61.7 10.0 238.0 228.0  15.1 233.6 218.5 201 201
161 1   3 -3.9 -2.3 1.6 57.0 61.7 10.0 238.0 228.0  15.1 233.6 218.5 201 201
179 1   6 -3.5 -0.7 2.8 58.6 60.1  7.0 235.0 228.0  12.2 230.6 218.4 200 201
197 1   5 -2.8 -0.1 2.7 59.2 59.5  5.9 233.9 228.0  11.1 229.5 218.4 201 201
215 1   0 -2.5  0.8 3.3 60.2 58.5  4.0 232.0 228.0   9.3 227.6 218.3 202 202
233 1  -4 -2.6  0.0 2.6 59.4 59.2  5.4 233.4 228.0  10.7 229.0 218.3 202 201
239 1  -4 -2.6 -0.3 2.3 59.0 59.6  6.0 234.0 228.0  11.3 229.6 218.3 202 201

avg roll adj=2.2 stdv=0.6 cnt=41
```

APPENDIX 5. Geographic Calculations

5.1 geomim

```
USAGE: geomim NN (AIM opO ihH caA)
EXAM   geomim 01
INPUT  \AIM\filNN.d
OUTPUT \AIM\geoNN.d
applys geom corrn for pit yaw roll lat lon alt
generates xi=km along orbit,yi=km perp orbit and pathlen
op1   1 (debug test program with interactive p y r om)
ihH   H is height of horizon (150 for ionosph horizon)
caA   A reduce scan angle by A for high resolution reduced area (not
      implemented)
```

generates a 41 x 41 matrix of geographic km from orbit nadir for each image line and column

Terminal output from geomim

```
 C:\BIB\BIN\GEOMIM.EXE 06
 options-
 opt=0 clipan=0 horht=0

Definitions
ang      degrees from nadir to point
kmE      km from nadir
kmS      km from first line nadir
path     vertical=1.0

matrix row = 0 image lin= 0 p=   1 y=    1 r=   -2 alt=1019 kmS=    0 hion=150
nadir ang=    2.2 col=123.6 kmS= -12.0
matrix col       0     5    10    15    20    25    30    35    40
image  col      14    40    67    93   120   148   176   205   233
ang            -57   -42   -28   -14     0    15    30    46    61
kmE          -2005  -924  -520  -253   -32   200   473   884  2005
kmS            -39   -23   -18   -15   -12   -10    -7    -4     3
100 path        21    59    81    94    99    96    83    61    21

matrix row=20 image lin=119 p=   2 y=   -8 r=   -1 alt=1027 kmS=2142 hion=150
nadir ang=    1.5 col=122.5 kmS=2116.0
matrix col       0     5    10    15    20    25    30    35    40
image  col      13    39    66    93   120   147   175   203   231
ang            -58   -43   -29   -14     0    15    30    45    60
kmE          -2003  -917  -512  -245   -22   207   478   886  1994
kmS           2385  2239  2185  2149  2119  2088  2051  1993  1826
100 path        21    59    81    95    99    96    83    61    21

matrix row=40 image lin=238 p=   1 y=    1 r=   -0 alt=1033 kmS=4284 hion=150
nadir ang=    0.3 col=120.6 kmS=4263.5
matrix col       0     5    10    15    20    25    30    35    40
image  col      11    38    65    92   120   147   174   202   229
ang            -59   -44   -29   -14     0    14    29    44    59
kmE          -2021  -916  -505  -233    -5   224   497   908  2017
```

```
kmS           4412 4331 4301 4281 4264 4246 4225 4192 4097
100/path        21   60   82   95   99   95   82   60   21
```

5.2 solel

```
USAGE: solel NN  (AIM)
EXAM:  solel 01
 INPUTS   \AIR\hdrNN.d  \AIR\geoNN.d
 OUTPUT   \AIR\selNN.d   41x41 sin_sol_el
```

Terminal output

```
C:\BOB\BIN\SOLEL.EXE 06
rolad=  2.20 rot=0
rho0=  91.5 sg=   0.1 cnt=    30
lam0= 327.2 sg=   0.6 cnt=    31
Center Lat= 69.4 Lon= 326.4
lalox lon=145.5 diff=180.9 correcting by 180
Day= 47 LMT=  9.86  Solar_noon lat= -13.2 lon= 358.5
```

definitions

```
xi         km along orbit from nadir first line
yi         km perp to orbit from nadir current line
sinse      100 * sin(solel)
```

matrix samples

```
il= 0
ik           0    1    5   10   15   20   25   30   35   39   40
sc ang-57.3-54.4-43.0-28.6-14.3  0.0 15.4 30.8 46.3 58.6 61.7
im col      14   19   40   67   93  120  148  176  205  227  233
xi/10       -3   -3   -2   -1   -1   -1   -1    0    0    0    0
yi/10     -200 -161  -92  -52  -25   -3   20   47   88  159  200
lat         72   75   81   85   87   88   88   86   82   76   73
lon        241  242  246  252  265  300   10   36   46   51   52
sinse        0    0    0    0    0    0    0    0    0    0    0
il=20
sc ang-58.1-55.2-43.6-29.0-14.5  0.0 15.2 30.3 45.5 57.6 60.7
im col      13   18   39   66   93  120  147  175  203  225  231
xi/10      238  233  223  218  214  211  208  205  199  189  182
yi/10     -200 -161  -91  -51  -24   -2   20   47   88  158  199
lat         61   63   67   68   69   69   70   70   69   67   66
lon        288  293  305  314  320  325  331  338  349    4   12
sinse        0    0    2    4    6    7    9   10   13   16   18
il=40
sc ang-59.1-56.1-44.3-29.5-14.8  0.0 14.9 29.8 44.7 56.6 59.6
im col      11   16   38   65   92  120  147  174  202  224  229
xi/10      441  438  433  430  428  426  424  422  419  413  409
yi/10     -202 -161  -91  -50  -23    0   22   49   90  161  201
lat         46   47   49   49   50   50   50   50   50   49   49
lon        301  306  314  320  323  327  330  334  339  349  354
sinse       20   23   29   32   34   35   37   39   41   45   47

Solar elev at image ctr=4.0 sin=0.070
```

5.3 warpim

```
USAGE: warpim NNDp (AIM opN)
reads selNN.D and geoNN.d
generates ground map
by applying geom corrn for pit yaw roll lat lon alt
NOTE expects filtered image filNN.iD in qu1
 opN n=0 200*sinel and 200/path to qu4
         then move q4 to selNN.i for geomlsq
     n=1 warps image to q2
         put rawNND into q3
         histogs and computes amplif
         reports wvln Rayl amp into \aim\ampNNDp.d
         then move q2 to warNNDp.i for geomlsq
     n=2 both warps
EXAM warpim 01 for solel image
EXAM warpim 012a op1 for war012a.i scene
```

Terminal output

```
C:\BOB\BIN\WARPIM.EXE 06
100 * sin solar elev at 60 line spacing 0 0 7 26 47
kmscl     map size
xysc      scaling to 240 line x 240 col image
Nctr      km from first line nadir
Ectr      km from center line nadir
kmscl 5000 xysc 0.048 Nctr 2119 Ectr -22
```

APPENDIX 6. Geomlsq

```
USAGE     geomlsq NND (AIM hiH loB  plP )
INPUTS    geoNN.d in qu2 selNN.i in qu4
OUTPUT    \AIR\lsqNND.d
  plP limit analysis to inv path pct > P (def= 25 == path 4)
  loB dont use inputs less than B (def=4)
  hiH H=1 report histogrammed occurrences of fit
  EXAM geomlsq 042
```

Terminal output

```
options-
geomlsq for AIR 062 hi1
```

histog of input

```
lut inverse path mn=46  mx=198 (200 = path 1.0)
lut sin(solel)   mn= 0  mx= 93 (200 = sin(solel)=1)
percent sunlit=63

reported as
p_mn 46 p_mx 198 s_mn 1 s_mx 93  pcsl 63
                                                               pct
                              tot med 99pctl              av    sg sg/av
nsI0  his tot med i99  3575   5 196 av sg pcsg/av  21.1  42.8  202
slI0  his tot med i99  6160  47 201 av sg pcsg/av  62.8  42.4   67

stored cnt path sel for sampling
total getvals =  4500
fit to log10(cnt)=C0 + Cp * log10(1./path) + Cs * log10(200.*sel)

sdv0   std dvn inputs
sdvf   std dvn after fit
pcvr   perct variance remaining
C01    C0 converted to 10**C0 and normalized to path=1 sel=0.01
pcsd   std dvn after fit converted from log10 to ± pct of value
pts    points fitting within ± limit

      (lg)C0  sdv0  sdvf  pcvr      C01      Cp      Cs  pcsd   pts
sunlit force Cp= -1 Cs=0.5
first fit
fc sl    3.02  0.17  0.15    73     7.39  -1.00   0.50    41  1675
screened fit
fc sl    2.97  0.23  0.09    14     6.55  -1.00   0.50    22  2449

sunlit free fit
first fit
ls sl    2.97  0.17  0.13    53    14.37  -0.82   0.27    34  1675
screened fit
ls sl    2.77  0.22  0.09    15     9.38  -0.84   0.41    22  2466

histogram of samples
sunlit samples=822
log br below =log(br)-0.5*log(sel)
no_s=0 samples=822
histog cell above 9 (A=10-19 B=20-29 ..)
```

```
  log pinv          1.7        1.9        2.1        2.3
      path          4.0        2.5        1.6        1.0
 lgbr   br
 0.60   4 .          .          .          .      AE.
 0.65   4 .          .          .          . 3  2ABCD.
 0.70   5 .          .          .         1128BACBBE.
 0.75   6 .          .          .       157BBBAAAAAA.
 0.80   6 .          .          . 2 112AABB93765757A.
 0.85   7 .          .    1   1 1 2 1BAAA64A56234167.
 0.90   8 .          .   11 12137553AA7964732714385.
 0.95   9 .          . 2   11 15585547A796511223346A.
 1.00  10 .          .123 13365334856325 .22 3 1212.
 1.05  11 .          122153545463 3341 41.2  211  2.
 1.10  13 .          2263651747.22  141 1. 1 2 11  .
 1.15  14 .          23435811312  2       113111 1 1.
 1.20  16 .          445533 1   .  1       11      1 .
 1.25  18 .          52121      .1     11  . 11   111.
 1.30  20 .          2 1       1.       1 1   11  1 .
 1.35  22 .          .   1      .1      11.         .
 1.40  25 .          .          .     1 1 .  1      .
 1.45  28 .          .1         .    12 1 .1        .
```

no sun fit

```
         (lg)C0  sdv0  sdvf  pcvr     C01     Cp     Cs  pcsd   pts
first fit
ls ns     1.01   0.16  0.16   100    6.08  -0.10   0.00    46   503
screened fit
ls ns     1.03   0.13  0.13    99    5.80  -0.12   0.00    36   565
```

```
histogrammed samples
no_sun samples=189
no_s=1 samples=189
histog cell above 9 (A=10-19 B=20-29 ..)
```

```
  log pinv          1.7        1.9        2.1        2.3
      path          4.0        2.5        1.6        1.0
 lgbr   br
 0.60   4 .          .          .    163895966324334A.
 0.65   4 .          .          . 212545553216424687.
 0.70   5 .          .          .          .        .
 0.75   6 .          .         1.     1234 343432343A.
 0.80   6 .          .          23 113131 4251312377.
 0.85   7 .          .          .          .        .
 0.90   8 .          .          . 22   332 211 312427.
 0.95   9 .          .       1   2 21132   2.  1 13155.
 1.00  10 .          .       2   2131 32 1 . 1 1 1324.
```

reimaging to q1 q2 with aur thr=47 slsgrat=143 dksgrat=171

histogram after reimaging

```
sibr   his tot med i99 19931   42 143 av sg pcsg/av   51.8   28.2   54
nsbr   his tot med i99 12529    4  31 av sg pcsg/av    8.5    8.5   99
aubr   his tot med i99  4396  117 224 av sg pcsg/av  124.1   53.7   43
sift   his tot med i99 19929  101 199 av sg pcsg/av  107.3   24.2   22
nsft   his tot med i99 12531   99 239 av sg pcsg/av  123.0   82.1   66
```

```
opening \AIR\lsq062.d for output

   AIR   Site    Day  GMTC    LMT  Linp  LatC  LonC    Dir
   062    SON    047 12.10   9.86   229  69.4 326.4      S
  Radj    Wvl   Rayl  mxse   Ampk  Araw  Afil  pcsl   pcau
   2.2   1356     30    48  1.000  7.82  46.7    63     12

 source   pts      avg     sig       med   pc_sig/avg
 slbr    19931     51.8    28.2       42           54
 nsbr    12529      8.5     8.5        4          100
 aubr     4396    124.1    53.7      117           43
 slft    19929    107.3    24.2      101           23
 nsft    12531    123.0    82.1       99           67
```

APPENDIX 7. Multiband Process

mulbnd help

```
USAGE mulbnd  stS blB whW opX klK khK llL lhL bgB
scales inputs qu12(3) to output screen 4 coded-color
opX    use in 2-color inputs
       X=1 shows color without brightness scaling X=2 same with black for
       zero vals
reports histograms from klK to khK and llL to lhL
stS S=0 no stretch (each assumed pre-scaled 0-255) S > 0 stretch S pctl to
     254*S/100
     S < 0 histog equ with stretch cmpc**abs(S)
     bgB 'bug' special use in 2-color inputs
      B = 2 reports input hists output stretch luts and quits
      B = 1 generates stretched quad 1 and 2 onto quad 3 and 4 count only
from blB (def=0) to whW (def=255)
EXAM mulbnd qu1204 (default 2-color 1 and 2 to output 4) EXAM mulbnd qu2143
(3-color 2 1 4 to output 3)
```

Terminal output

```
C:\BOB\BIN\MULBND.EXE
options-
mulbnd fi= 1 2 0 fo=4 op=0 st=0 bg=0

histogram report
band=1 samples 0=10362 1=15436 255=160 histog other=28800
band=2 samples 0=10362 1=16273 255=0   histog other=28800
histog of band1 vs band2 values mx=122 excluding 0's
```

band1 \ band2	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210
0	99	0	2	99	55	37	38	28	19	21	25	17	7	3	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	99	0	0	18	4	1	0	0	0	0	0	0	0	0	0
60	99	0	4	66	40	4	1	0	3	6	0	1	0	0	0
75	99	0	0	53	32	12	0	1	0	1	2	0	0	0	0
90	75	0	0	19	18	25	0	4	1	3	4	1	1	0	0
105	56	0	1	22	15	15	12	6	0	1	1	0	0	0	0
120	55	0	3	11	17	19	6	6	4	9	2	4	0	0	0
135	63	0	0	15	14	15	7	7	5	6	10	1	0	0	0
150	47	0	0	12	10	4	4	11	6	6	16	3	0	0	0
165	17	0	0	9	16	22	2	9	14	17	9	9	1	0	0
180	7	0	0	9	13	4	7	16	22	11	17	10	5	0	0
195	0	0	0	13	4	3	6	9	9	13	31	26	6	0	0
210	7	0	0	1	4	6	2	19	33	34	94	99	50	26	0

Note to equalize signal response:

hiseq histogram equalize

band1

cmpc	0	1	2	10	50	80	90	95-100
ival	0	64.9	65.2	69.0	135	222	248	255
lut	0	3.5	4.7	21.1	127	204	229	255

band2

cmpc	0	1	2	10	50	80	90	95	98	99	99.5	99.8	100
ival	0	51.0	53.1	59.0	122	182	197	206	219	222	224	234	237
lut	0	1.0	4.4	23.1	127	204	228	242	250	252	254	255	255

mulbnd of histogram-equalized bands
Note improved distribution of data

band=1 samples 0=25854 1=0 255=160 histog other=28800
band=2 samples 0=26643 1=9 255=23 histog other=28800
histog of band1 vs band2 counts mx=65 excluding 0's

band2=0 15 30 45 60 75 90105120135150165180195210

band1															
0	99	86	69	50	59	38	84	61	33	39	23	33	16	24	21
15	99	6	21	16	6	0	0	1	0	1	0	0	0	0	0
30	99	7	4	7	9	3	3	0	0	0	0	0	0	0	0
45	99	13	15	19	12	3	0	0	4	4	0	1	0	0	0
60	99	13	6	15	18	9	1	1	0	0	7	0	4	3	0
75	99	21	35	19	13	12	3	12	3	4	1	0	0	0	0
90	99	15	27	16	21	43	15	1	3	0	4	10	3	0	3
105	99	7	1	16	18	24	41	7	7	4	3	1	4	3	0
120	99	4	9	15	26	29	26	7	23	10	13	6	7	1	0
135	96	4	18	10	10	4	12	27	15	10	16	19	4	3	0
150	58	6	10	4	32	21	24	16	19	38	12	10	26	6	6
165	19	6	12	24	7	9	7	36	23	35	15	29	16	12	13
180	3	12	6	1	0	6	6	33	16	35	29	32	43	46	16
195	13	0	0	0	6	0	6	6	27	26	46	44	66	39	99
210	0	0	0	0	0	0	0	0	13	23	7	35	52	50	63

APPENDIX 8. Batch Processes MULP and MULD

Listing of MULP.BAT

```
rem USAGE mulp NN 1 2
rem mulp prepares 2-band colored images from raw\air images
rem muld demonstrates using images prep by mulp for fast demo
rem processes via unpak filtraw warpim geomlsq mulbnd
rem rerun can bypass parts with 'goto aa etc'
rem final images puts landmass squishes to square and titles
rem CR if raw%1%2 raw%1%3 OK else CNTRL C
```

batch command	purpose
if not exist \air\raw%1%2.i goto err1	test if present
if not exist \air\raw%1%3.i goto err1	"
modlut cw	set display to 4-wedge color
rem geomim solel warpim op0 once only	
rem serves all bands	
rawfit %1	prepare fil%1.d orbit and hdr%1.d
geomim %1	prepare 40x40 matrix km geoNN.d
solel %1	prepare 40x40 matrix solel selNN.d
warpim %1	prepare image lut of path and sel
moveim 45 \air\sel%1.i	store
rem now proc %1%2	
moveim 52 \air\raw%1%2.i	xfer raw%1%2 image to q2
unpak 21 %1%2	unpack packed values
moveim 15 \air\unp%1%2.i	store
if %2 == "1" filtraw n7	filter raw image (det 1 wid=7)
if not %2 == "1" filtraw n3	filter raw image (det 2,3 wid=3)
moveim 45 \air\fil%1%2.i	store
moveim 53 \air\unp%1%2.i	move unp to q3
moveim 51 \air\fil%1%2.i	move fil to q1
warpim %1%2 op1	warp to q3 and compute amplif
moveim 25 \air\war%1%2.i	store
moveim 52 \air\war%1%2.i	move warped to q2
moveim 54 \air\sel%1.i	move sel lut image to q4
geomlsq %1%2	lsq fit to path and sel
moveim 15 \air\agl%1%2.i	store airglow
moveim 35 \air\aur%1%2.i	store aurora
rem now proc %1%3	
moveim 52 \air\raw%1%3.i	repeat for NND D=%3
unpak 21 %1%3	
moveim 15 \air\unp%1%3.i	
if %2 == "1" filtraw n7	
if not %2 == "1" filtraw n3	
moveim 45 \air\fil%1%3.i	
moveim 53 \air\unp%1%3.i	
moveim 51 \air\fil%1%3.i	
warpim %1%3 op1	
moveim 25 \air\war%1%3.i	
moveim 52 \air\war%1%3.i	
moveim 54 \air\sel%1.i	
geomlsq %1%3	

```
moveim 15 \air\agl%1%3.i
moveim 35 \air\aur%1%3.i
moveim 53 \air\aur%1%2.i                 prepare for multi-bnd aurora
moveim 54 \air\aur%1%3.i
hiseq 31 h1 b2
hiseq 42 h1 b2                           hiseq aurora
mulbnd                                   prepare coded image
if exist \air\lm%1.i goto lmx
landmass q3 a%1                          prepare landmass overlay
moveim 35 \air\lm%1.i                    store
:lmx
moveim 53 \air\lm%1.i                    recover
overlim 31                               overlay landmass on aur qd2
overlim 32                                  "                    qd3
overlim 34                                  "                    qd4
moveim 13                                prepare 'squished'
rotim 31 0 1.2 1
moveim 23
rotim 32 0 1.2 1
moveim 43
rotim 34 0 1.2 1
texthdr %1%2 1                          headers on quads
texthdr %1%2 2
texthdr %1%2 4
texthdr %1%2 1 1
texthdr %1%3 2 3
texthdr %1%2 4 2
texthdr %1%3 4 4
moveim 15 \air\dau%1%2.i                store
moveim 25 \air\dau%1%3.i
moveim 45 \air\dau%1%2%3.i
rem now display warped airglow+aurora
moveim 53 \air\war%1%2.i                recover warped filtered images
moveim 54 \air\war%1%3.i
hiseq 31 h1 b2                          hiseq
hiseq 42 h1 b2
mulbnd                                  mulbnd
if exist \air\lm%1.i goto lmy
landmass q3 a%1                         prepare landmass overlay
moveim 35 \air\lm%1.i                   store
:lmy
moveim 53 \air\lm%1.i                   get landmass
overlim 31                              overlay
overlim 32
overlim 34
texthdr %1%2 1
texthdr %1%2 2
texthdr %1%2 4
texthdr %1%2 1 1
texthdr %1%3 2 3
texthdr %1%2 4 2
texthdr %1%3 4 4
moveim 15 \air\dwr%1%2.i                store
moveim 25 \air\dwr%1%3.i
```

```
moveim 45 \air\dwr%1%2%3.i
rem his_eq and mulbnd scene NN D D
rem from raw and filtered images
moveim 53 \air\raw%1%2.i                  get rawNND D=1
hiseq  31 h1                              histog equalize
hiseq 32 s2                               stretch 2-998 permil 0-255
moveim 14
: q3 orig q1 hiseq q2 ampl
textim qu3 1134 fm1 orig  raw%1%2         overlay texts
textim qu4 1134 fm1 hiseq
textim qu2 1134 fm1 stretched
texthdr %1%2 3
texthdr %1%2 3 1
: store
moveim 25 \air\drs%1%2.i                  store
moveim 45 \air\drh%1%2.i
moveim 35 \air\drl%1%2.i

moveim 54 \air\raw%1%3.i                  repeat for rawNND D=%3
hiseq 42 h1
moveim 51 \air\drh%1%2.i
rdlut c2
mulbnd                                    mulbnd
texthdr %1%2 4
texthdr %1%2 4 2
texthdr %1%3 4 4
textim qu4 1134 fm1 raw hiseq 2-band
rem 2-band image
moveim 45 \air\dr2%1%2%3.i                store
rem now filtered
moveim 53 \air\fil%1%2.i                  repeat for filtered images
hiseq 31 h1
moveim 54 \air\fil%1%3.i
hiseq 42 h1
mulbnd
textim qu4 1134 fm1 fil hiseq 2-band
moveim 45 \air\df2%1%2%3.i
goto end
:err1
echo raw%1%2 or %1%3 not found
:end
beep 3
```

Listing of MULD.BAT

```
MULD.bat
rem USAGE muld NN D D
rem mulp prepares 2-band colored images from raw \air images
rem muld demos using images prep by mulbp for fast demo
rem processes via unpak filtraw warpim geomlsq mulbnd
rem rerun can bypass parts with 'goto aa etc'
rem final images puts landmass squishes to square and titles
rem CR if raw%1%2 raw%1%3 OK else CNTRL C
rem pausex
zoomim
modlut cw
moveim 51 \air\raw%1%2.i
hiseq 12 s10
textim qu1 sz2 fm1 raw%1 det%2
textim qu1 1134 fm1 orig
textim qu2 1134 fm1 stretched
moveim 53 \air\fil%1%2.i
textim qu3 1134 fm1 filtered
moveim 54 \air\war%1%2.i
textim qu4 1134 fm1 geom warped
pausex
moveim 51 \air\agl%1%2.i
textim qu1 sz2 fm1 raw%1 det%2
textim qu1 1134 fm1 lsq airglow
moveim 52 \air\aur%1%2.i
textim qu2 1134 fm1 lsq aurora
pausex
moveim 51 \air\raw%1%3.i
hiseq 12 s10
textim qu1 sz2 fm1 raw%1 det%3
textim qu1 1134 fm1 orig
textim qu2 1134 fm1 stretched
moveim 53 \air\fil%1%3.i
textim qu3 1134 fm1 filtered
moveim 54 \air\war%1%3.i
textim qu4 1134 fm1 geom warped
pausex
:qq
moveim 51 \air\agl%1%3.i
textim qu1 sz2 fm1 raw%1 det%3
textim qu1 1134 fm1 lsq airglow
moveim 52 \air\aur%1%3.i
textim qu2 1134 fm1 lsq aurora
pausex
moveim 51 \air\dwr%1%2.i
textim qu1 1134 fm1 aur + airg det %2
moveim 52 \air\dwr%1%3.i
textim qu2 1134 fm1 aur + airg det %3
rem now display hiseq aurora
moveim 53 \air\dau%1%2.i
textim qu3 1134 fm1 lsq aurora det %2
moveim 54 \air\dau%1%3.i
```

```
textim qu4 1134 fm1 lsq aurora det %3
pausex
modlut c2
moveim 51 \air\dwr%1%2%3.i
textim qu1 sz2 fm1 2-band geom
moveim 52 \air\dau%1%2%3.i
textim qu2 sz2 fm1 2-band aurora
pausex
zoomim
modlut cw
: read from disk
moveim 51 \air\drl%1%2.i
moveim 52 \air\drh%1%2.i
moveim 53 \air\drs%1%2.i
moveim 54 \air\fil%1%2.i
textim qu4 1134 fm1 filtered
pausex
rem black-white
modlut c0
pausex
modlut c2
moveim 51 \air\dr2%1%2%3.i
moveim 52 \air\df2%1%2%3.i
moveim 53 \air\dwr%1%2%3.i
textim qu3 1134 fm1 geom aurora+airglow
moveim 54 \air\dau%1%2%3.i
textim qu4 1134 fm1 geom aurora only
```

APPENDIX 9. Photographs

A series of color photographs have been taken from the monitor to document processing steps. The color images cannot be reproduced by an office photocopier but 4 sets have been prepared for 4 copies of this report.

Wedge at right of image top= 0 digital value bottom= 255 digital value

Display code

B_W Black to white
0 -> black 255 -> white
F_C False color wedges
0-63 -> red 64-127 -> yellow 128-191 -> green 192-255 -> blue
M_B Multi-band 2-detector display
red to grey to green

The first group were made from a 63 pct sunlit scene with 15 pct aurora
Scene_06 Det_1 1596_A N2 (LBH band) Det_2 1356_A OI

Photo	Quad	Disp	Det	Wvln	Process
1	1	F_C	2	1356	Rolladj Right Limb detection on Input
	2	B_W	2	1356	Rolladj Right Limb detection on Input
	3	F_C	2	1356	Warpim Edges of Ground Scene on Input
	4	B_W	2	1356	Warpim Edges of Ground Scene on Input
2	1	F_C	1	1596	Input Raw image (intensities too low to see)
	2	F_C	1	1596	Histog-equalized
	3	F_C	1	1596	Stretch (99 pctl to 255)
	4	F_C	1	1596	Filtered (by FILTRAW)
3		B_W display of Photo 2			
4	1	M_B	1,2		Hiseq raw 2-band
	2	M_B	1,2		Hiseq filtered 2-band
	3	M_B	1,2		Above warped to 5000 km ground map
	4	M_B	1,2		Above Aurora only
5	1	F_C	1	1596	Input Raw image (intensities too low to see)
	2	F_C	1	1596	Stretch (99 pctl to 255)
	3	F_C	1	1596	Filtered (by FILTRAW)
	4	F_C	1	1596	Above warped to 5000 km ground map
6	1	F_C	1	1596	Geomlsq 'normalized airglow'
	2	F_C	1	1596	Geomlsq aurora only
	Qd3 and Qd4 copy of of Photo 5				
7	1	F_C	2	1356	Input Raw image (intensities low)
	2	F_C	2	1356	Stretch (99 pctl to 255)
	3	F_C	2	1356	Filtered (by FILTRAW)

	4	F_C	2	1356	Above warped to 5000 km ground map
8	1	F_C	2	1356	Geomlsq 'normalized airglow'
	2	F_C	2	1356	Geomlsq aurora only
	Qd3 and Qd4 copy of of Photo 7				
9	1	F_C	1	1596	Geomlsq 'normalized airglow'
	2	F_C	2	1356	Geomlsq 'normalized airglow'
	3	F_C	1	1596	Geomlsq aurora only
	4	F_C	2	1356	Geomlsq aurora only
10	1	M_B	1,2		Geomlsq 'normalized airglow' 2-band
	2	M_B	1,2		Geomlsq aurora only 2-band
	Qd3 and Qd4 should be ignored				

The second group were made from a non-sunlit scene with 35 pct aurora
Scene_13 Det_2 1356_A OI Det_3 3914_A N2+

Photo	Quad	Disp	Det	Wvln	Process
11	1	F_C	2	1596	Input Raw image (intensities too low to see)
	2	F_C	2	1596	Histog-equalized
	3	F_C	2	1596	Stretch (99 pctl to 255)
	4	F_C	2	1596	Filtered (by FILTRAW)
12		B_W display of Photo 11			
13	1	M_B	2,3		Hiseq raw 2-band
	2	M_B	2,3		Hiseq filtered 2-band
	3	M_B	2,3		Above warped to 5000 km ground map
	4	M_B	2,3		Above Aurora only
14	1	F_C	2	1596	Input Raw image (intensities too low to see)
	2	F_C	2	1596	Stretch (99 pctl to 255)
	3	F_C	2	1596	Filtered (by FILTRAW)
	4	F_C	2	1596	Above warped to 5000 km ground map
15	1	F_C	2	1596	Geomlsq 'normalized airglow'
	2	F_C	2	1596	Geomlsq aurora only
	Qd3 and Qd4 copy of of Photo 14				
16	1	F_C	3	3914	Input Raw image (intensities low)
	2	F_C	3	3914	Stretch (99 pctl to 255)
	3	F_C	3	3914	Filtered (by FILTRAW)
	4	F_C	3	3914	Above warped to 5000 km ground map
17	1	F_C	3	3914	Geomlsq 'normalized airglow'
	2	F_C	3	3914	Geomlsq aurora only
	Qd3 and Qd4 copy of of Photo 16				
18	1	F_C	2	1596	Geomlsq 'normalized airglow'
	2	F_C	3	3914	Geomlsq 'normalized airglow'
	3	F_C	2	1596	Geomlsq aurora only

	4	F_C	3	3914	Geomlsq aurora only	
19	1	M_B	2,3		Geomlsq 'normalized airglow'	2-band
	2	M_B	2,3		Geomlsq aurora only	2-band

Qd3 and Qd4 should be ignored

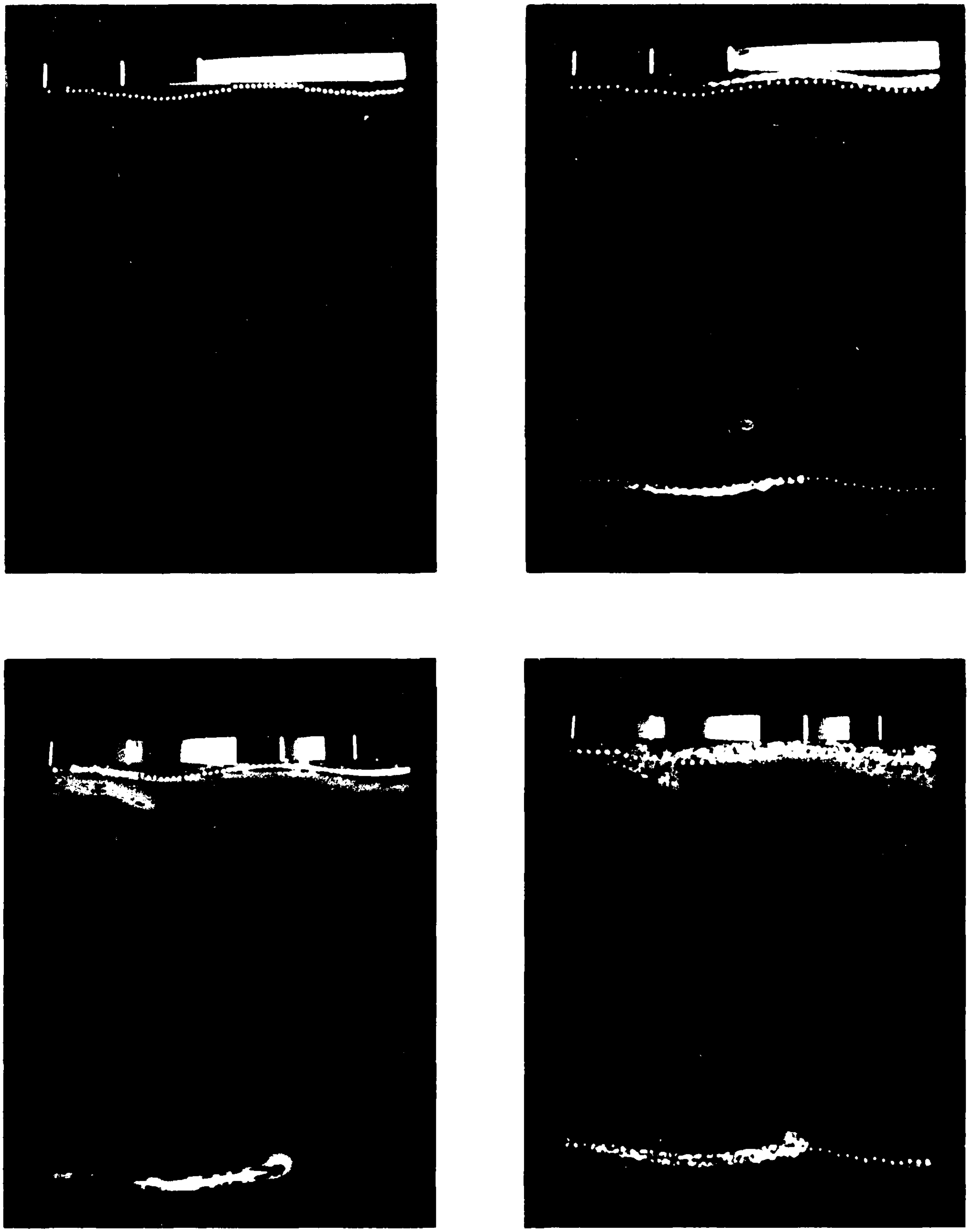
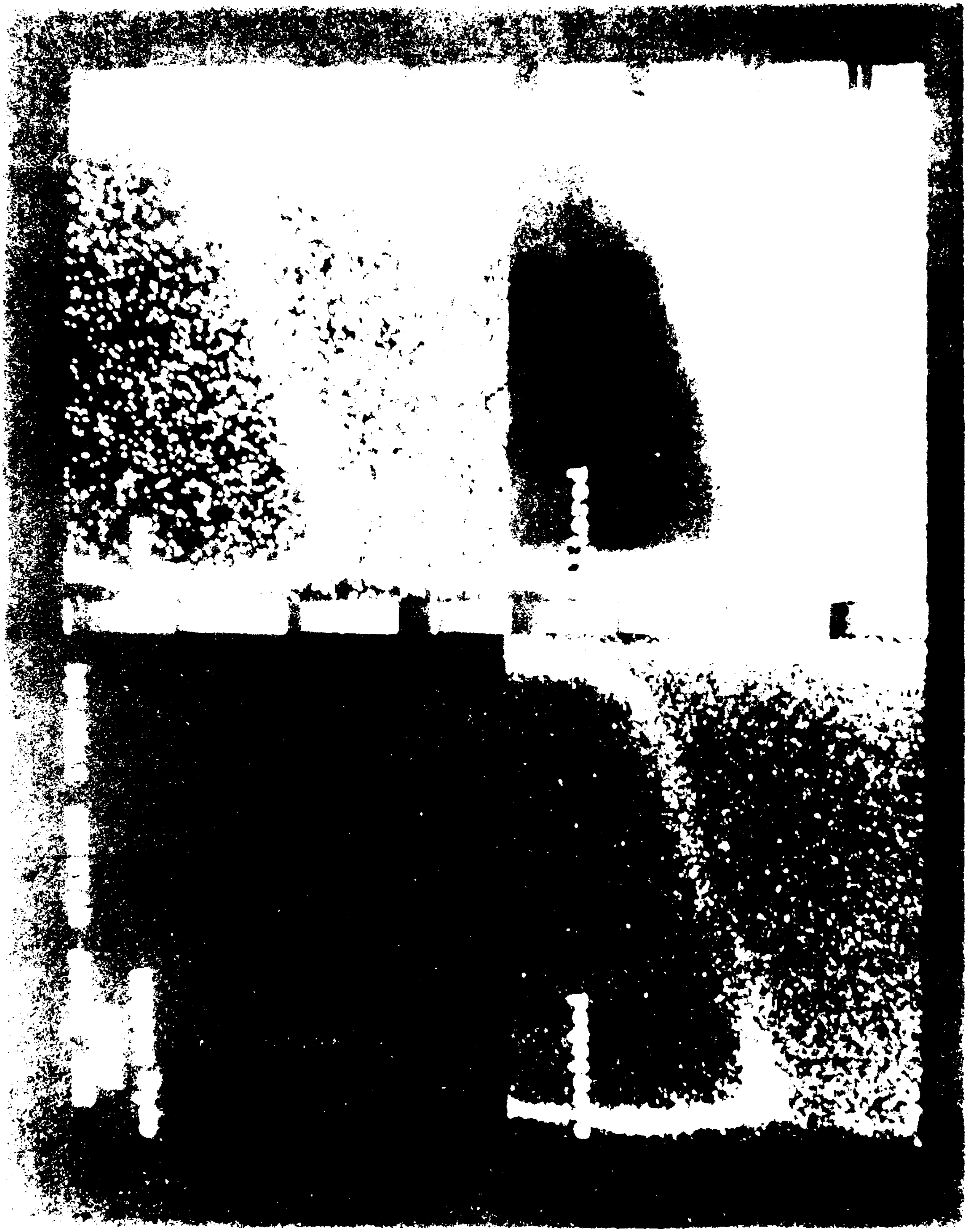


Photo 1



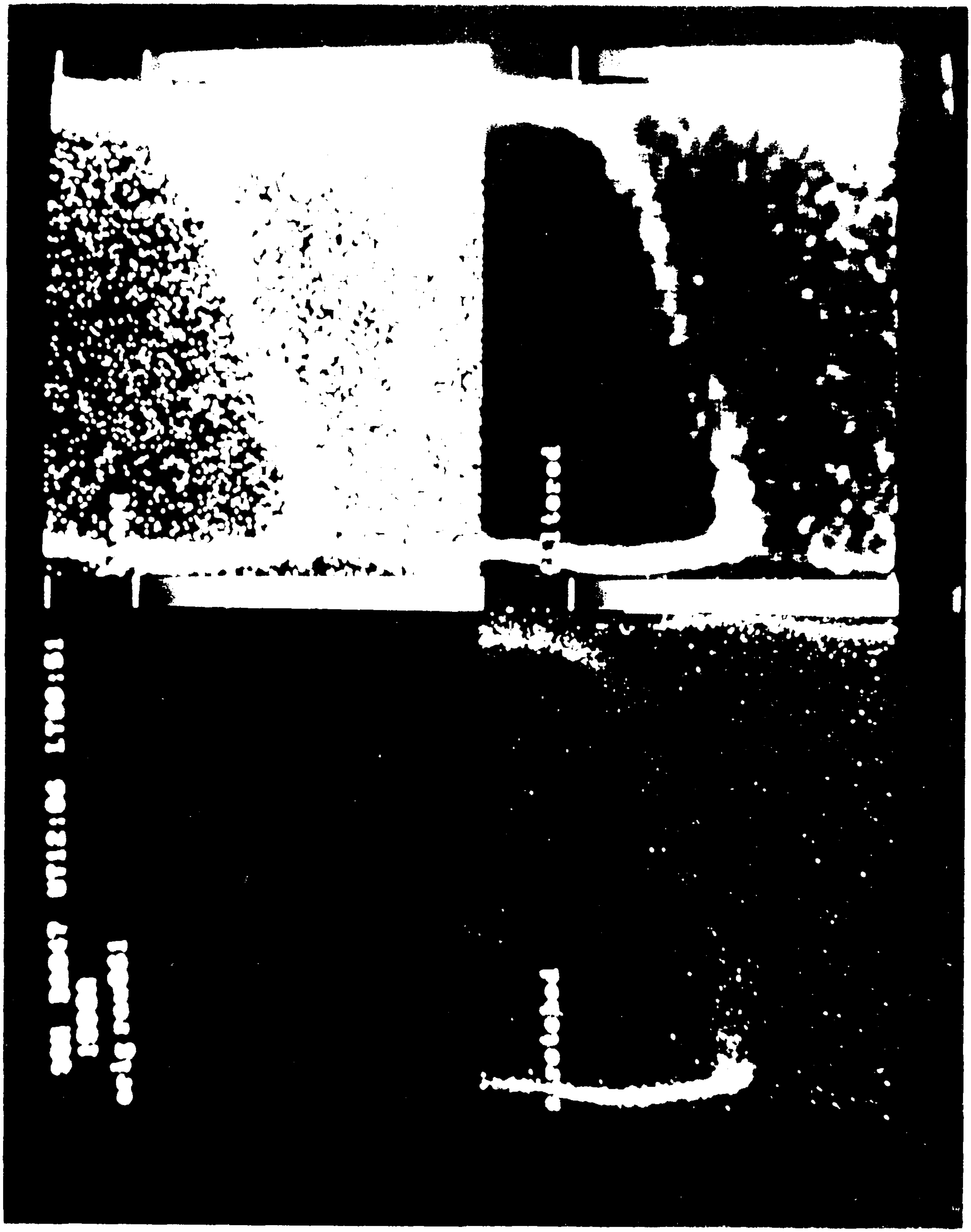


Photo 3

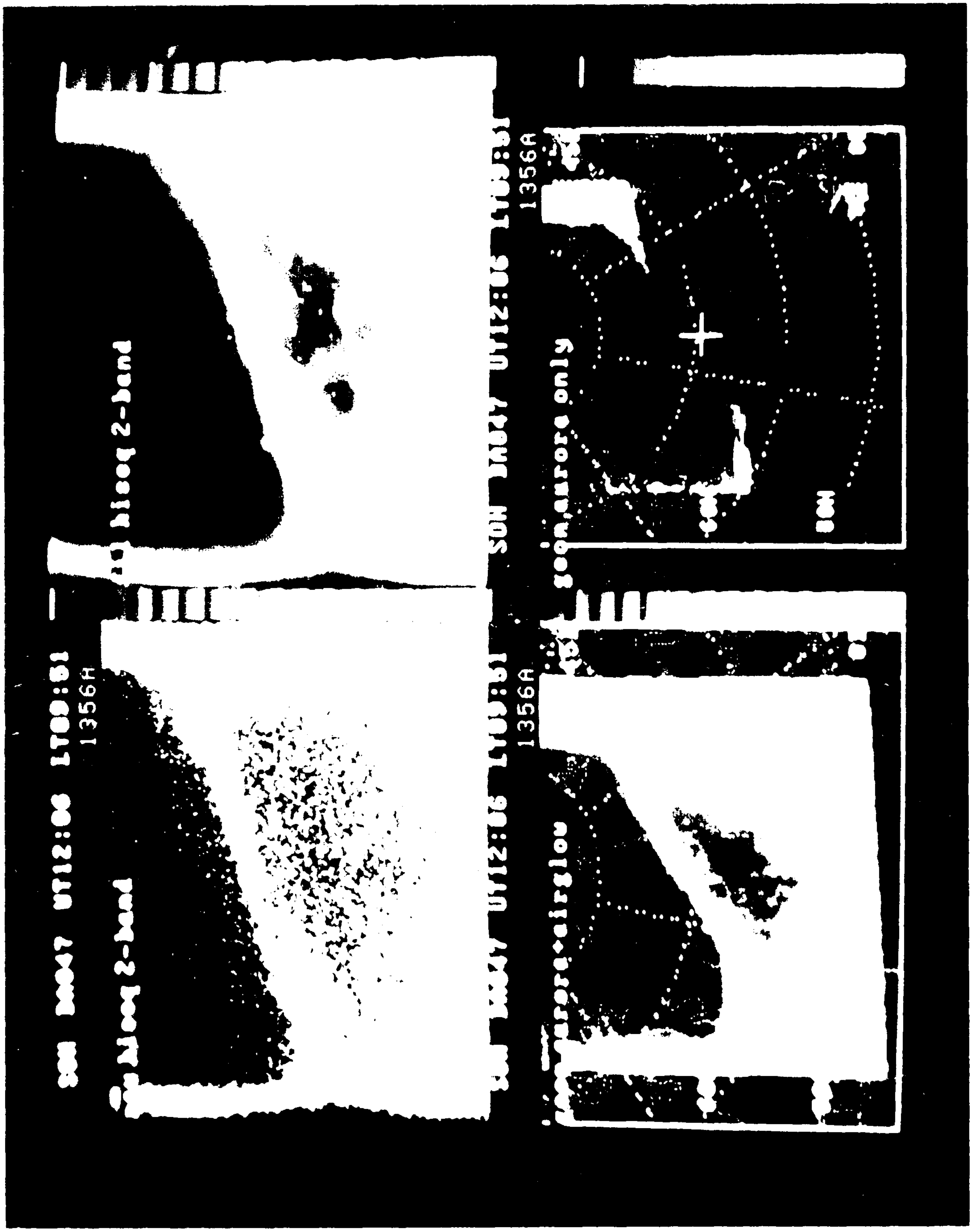


Photo 4

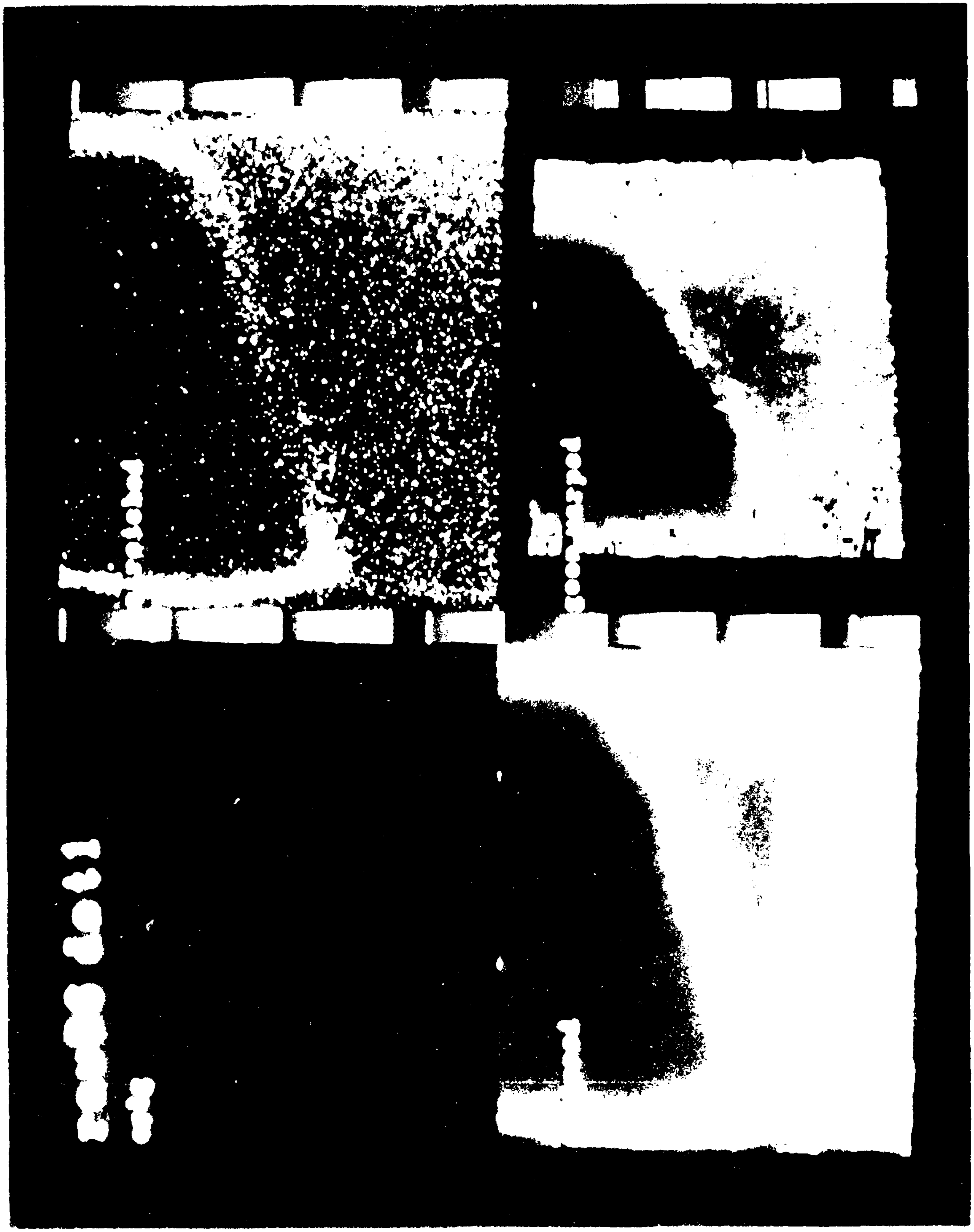


Photo 5

Photo 6

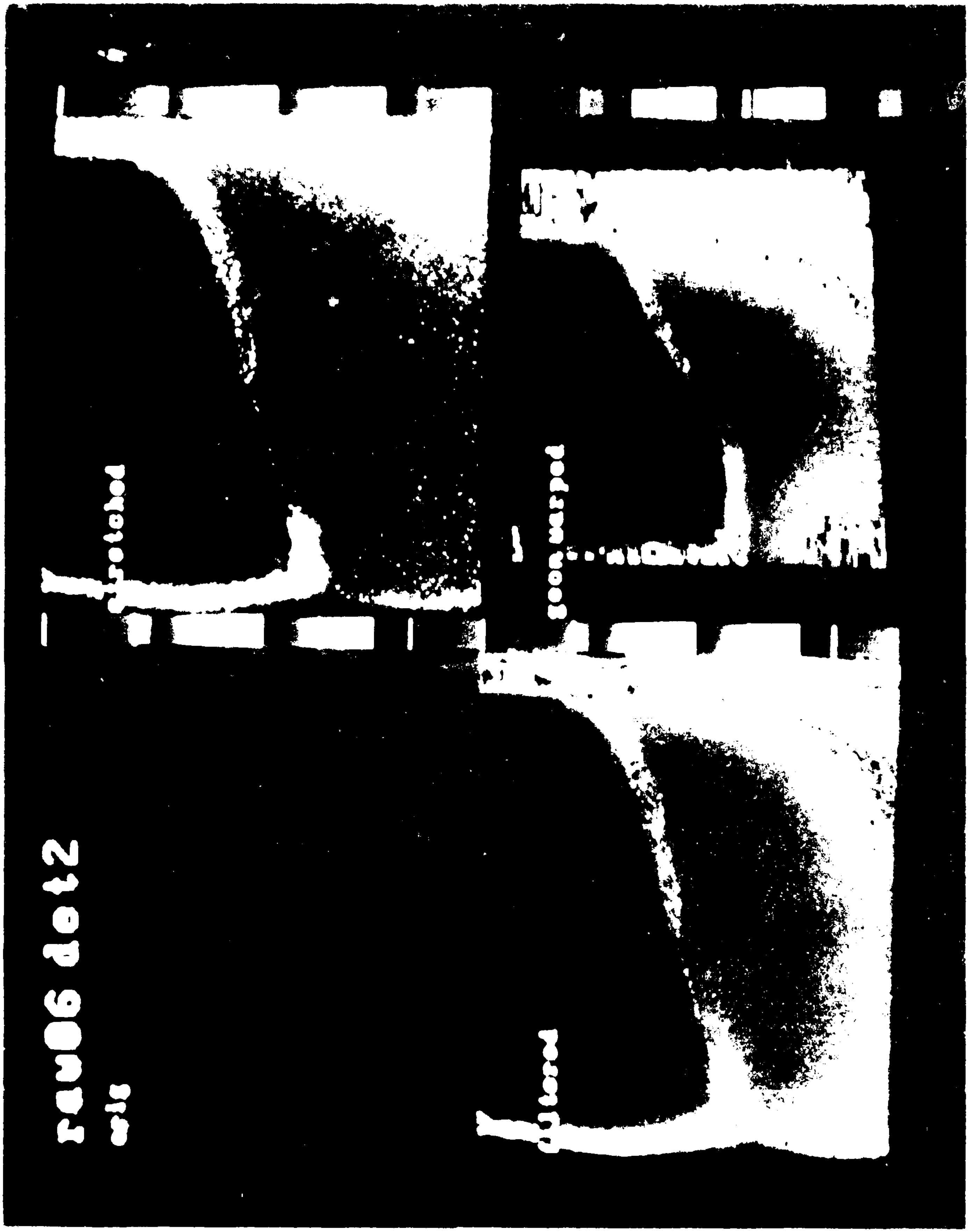


Photo 7

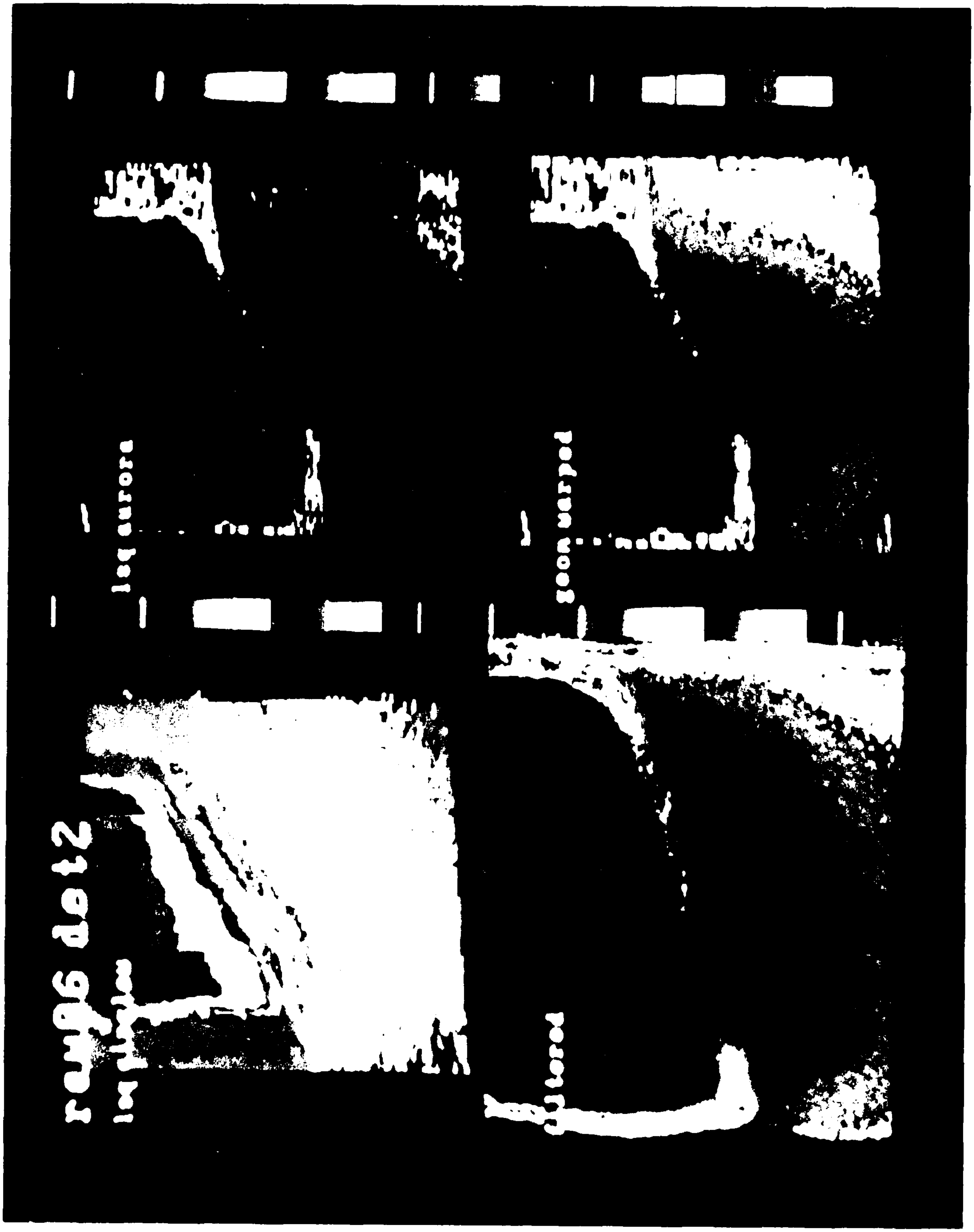
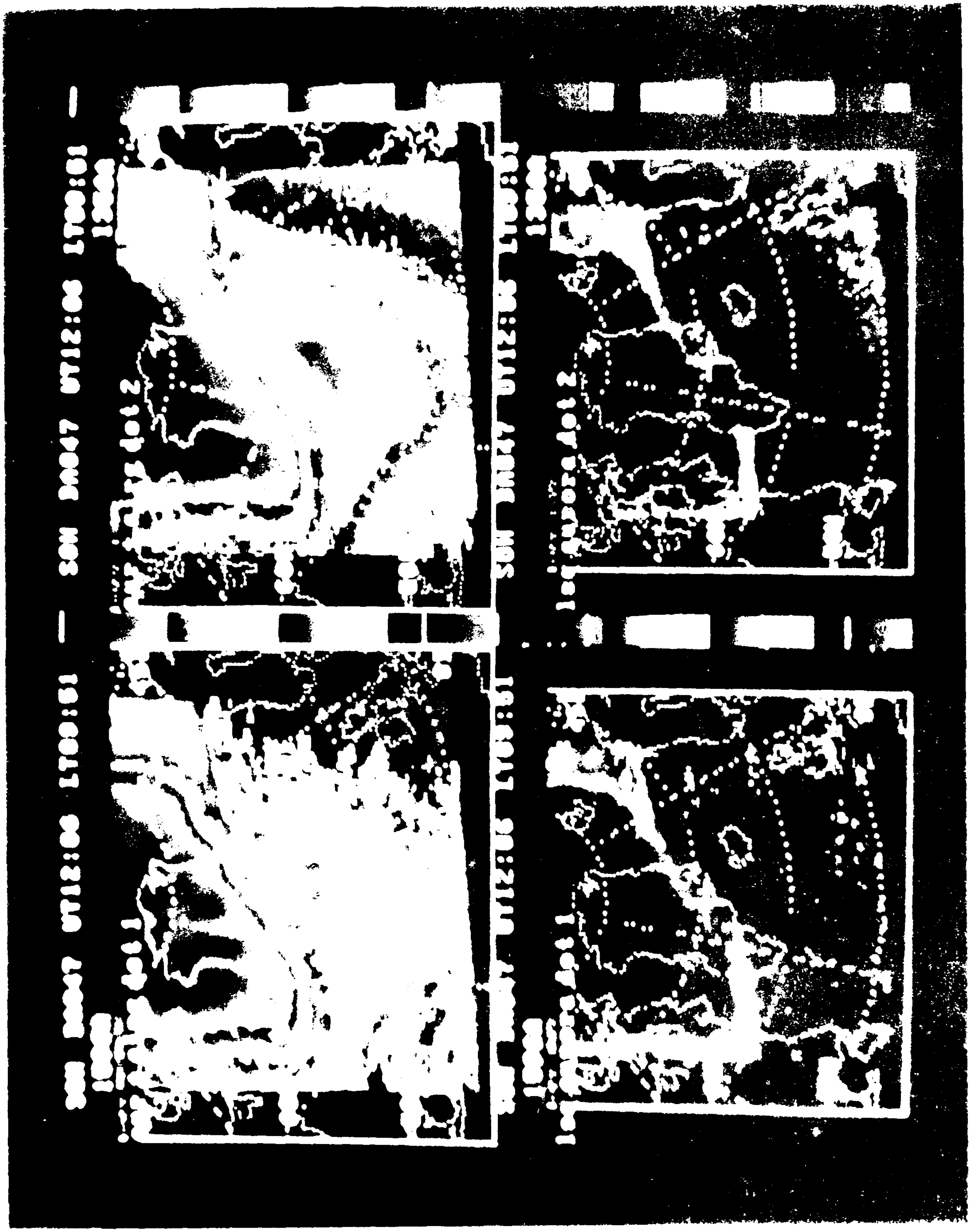


Photo 8



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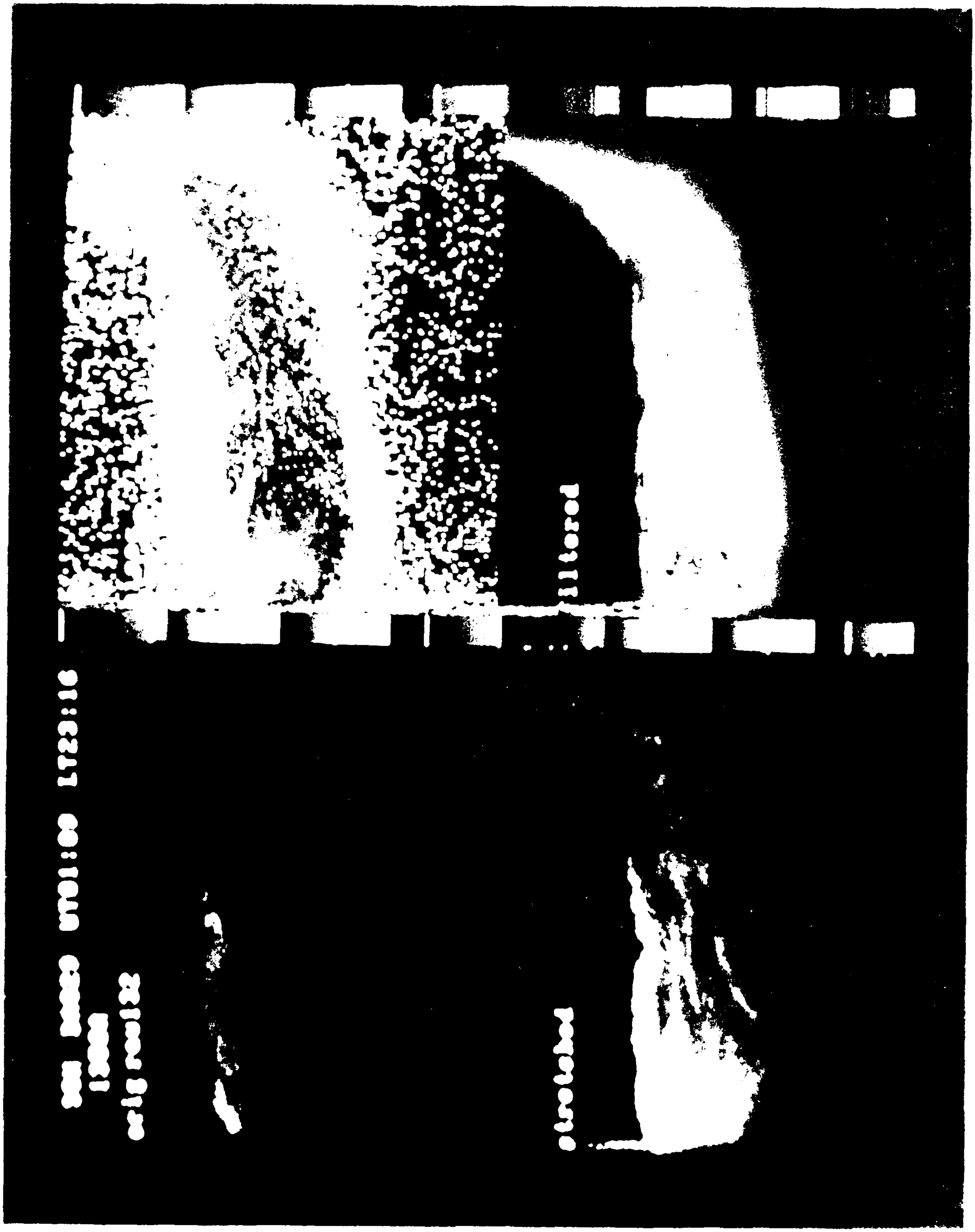


Photo 11

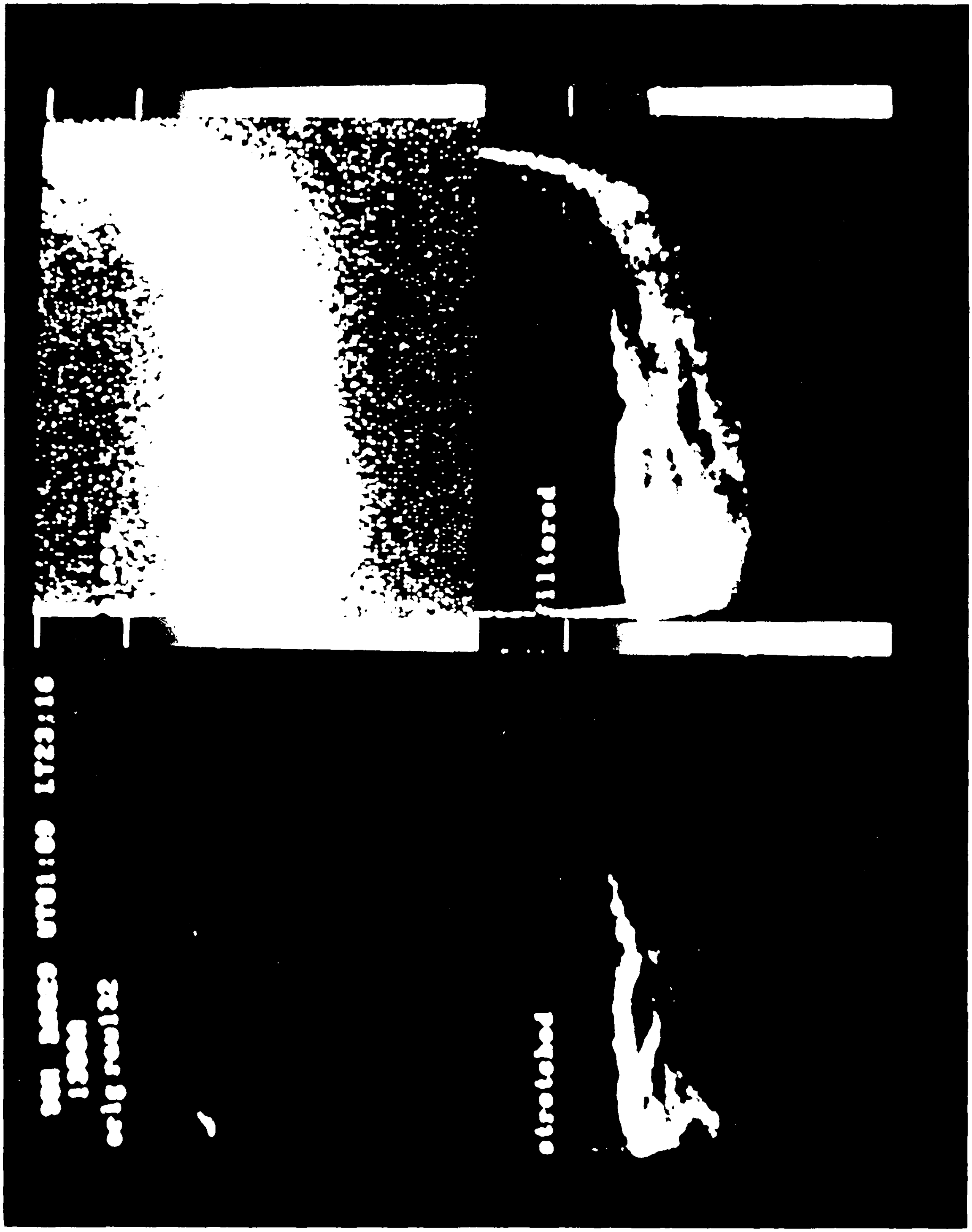


Photo 12

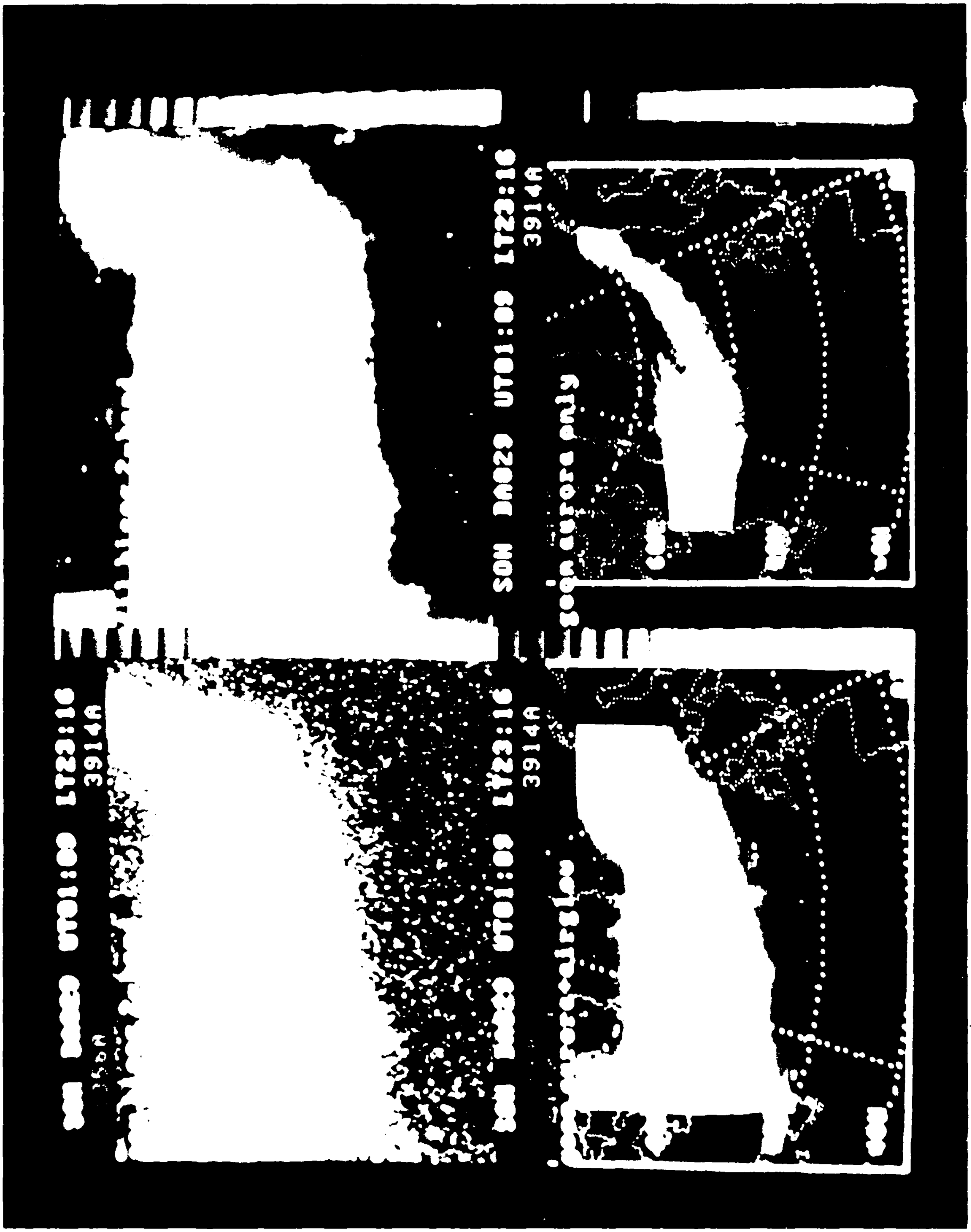
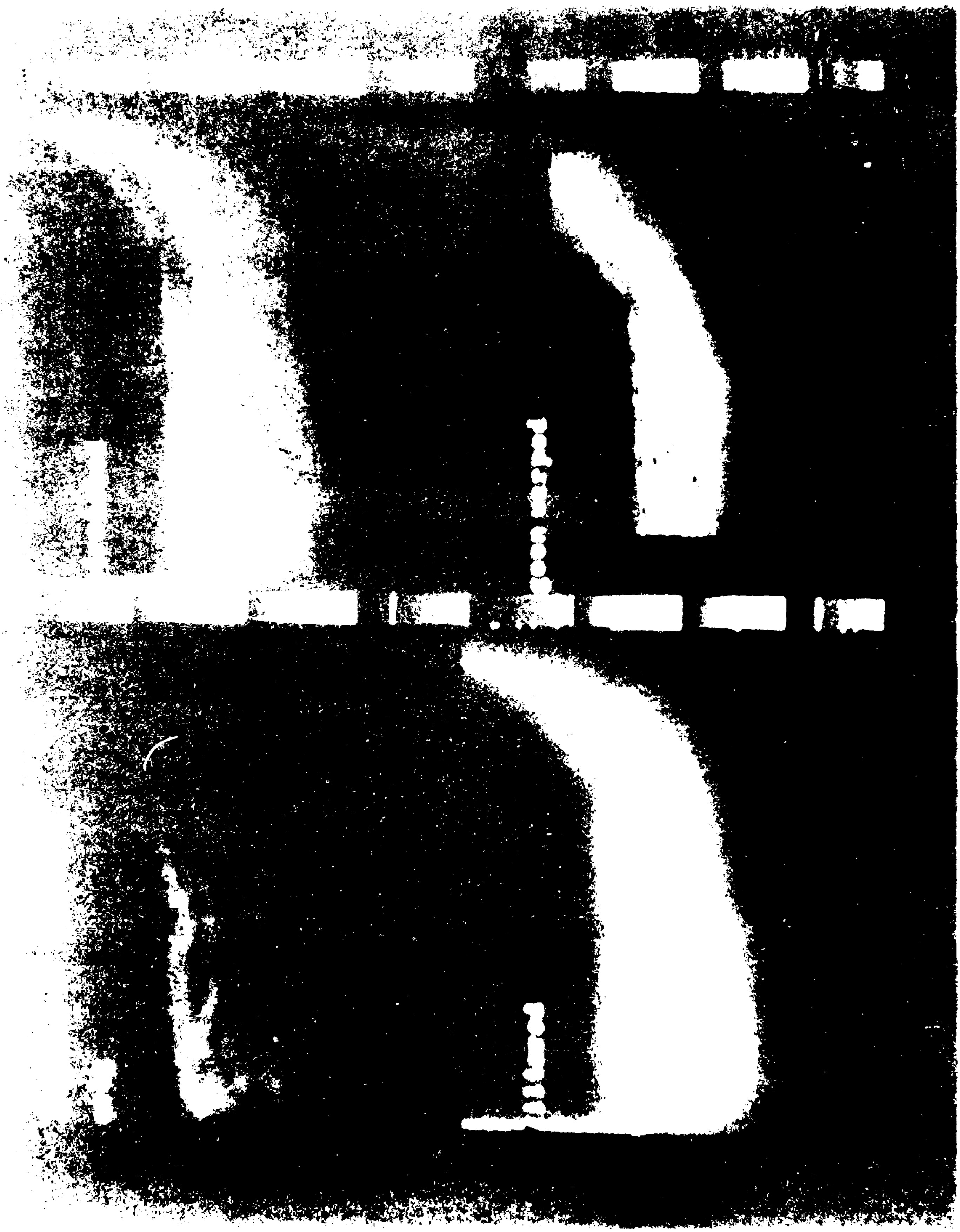
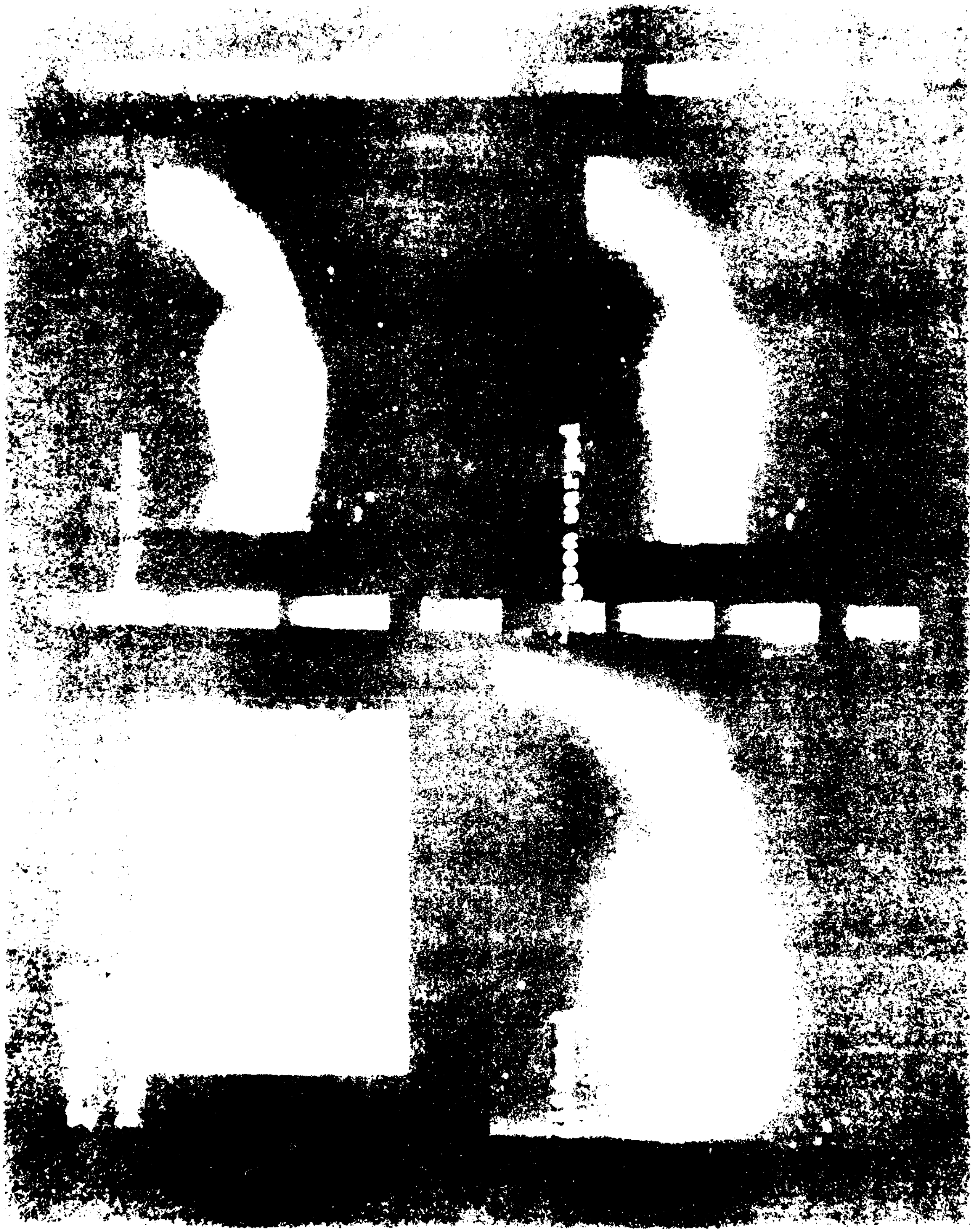


Photo 13





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